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HOURLY TRANSPIRATION RATE ON CLEAR DAYS AS DETERMINED BY CYCLIC ENVIRONMENTAL FACTORS

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INTRODUCTION

The great differences exhibited by various plants in water requirement—i. e., in the water transpired in the production of a unit of dry matter—are of profound economic importance in the agricultural development of regions of limited rainfall, and an understanding of what gives rise to the greater efficiency which some plants possess in the use of water is highly desirable in the selection and breeding of plant strains adapted to dry-land agriculture. This problem has led the writers to undertake a series of transpiration measurements with a view to determining, so far as possible, the relative influence of various environmental factors on the transpiration of different plants. To this end simultaneous automatic records have been obtained of the solar-radiation intensity, the depression of the wet-bulb thermometer, the air temperature, the wind velocity, and the evaporation from a free-water surface. The present paper deals with the transpiration response of plants to these factors on clear days.

DESCRIPTION OF APPARATUS AND METHODS

MEASUREMENT OF TRANSPIRATION

The transpiration measurements described in this paper were carried out at Akron, Colo., in 1912, 1913, and 1914 (Pl. LIII). Transpiration was determined by weighing, four large automatic platform scales of a type already described (Briggs and Shantz, 1915)[2] being used in these measurements. The plants employed were those used in the water-

[1] The writers desire to express their indebtedness to the following men for efficient and painstaking assistance in connection with data presented in this paper: Messrs. F. A. Cajori, R. D. Rands, A. MacG. Peter, J. D. Hird, R. L. Piemeisel, P. N. Peter, H. W. Markward, G. Crawford, and H. Martin.

[2] Bibliographic citations in parentheses refer to "Literature cited," p. 648-649.

requirement investigations, and were grown in the sealed pots already described (Briggs and Shantz, 1913, p. 9), which practically eliminate the direct loss of water from the soil. The pots contained about 115 kgm. of soil and were sufficiently large to enable the plants to make a normal growth, a factor of importance in transpiration measurements (Pl. LV, figs. 1–2). A part of the transpiration measurements were made within the screened inclosure (Pl. LIV, fig. 1) used in the water-requirement experiments to protect the plants from hail and wind storms. Other measurements were made outside the inclosure where the plants were freely exposed, with no protection whatever (Pl. LIV, fig. 2).

MEASUREMENT OF PHYSICAL FACTORS

SOLAR RADIATION.—The solar-radiation measurements were made automatically with a mechanical differential-telethermograph already described by one of the writers (Briggs, 1913). The instrument has two independent cylindrical bulbs and records only the difference in temperature of the two bulbs. When used for measuring radiation intensity, one bulb is blackened and surrounded by a spherical glass envelope (Pl. LIII). This is so exposed to the sun that the longer diameter of the bulb is normal to the sun's rays at midday. This bulb rises in temperature until the rate at which energy is lost is equal to the rate at which it is received. The other bulb follows the temperature of the air within the instrument shelter, through which the wind blows freely. The instrument was calibrated by comparison with an Abbot silver-disk pyrheliometer (Abbot, 1911). Such comparison shows that the difference in temperature, as measured by the telethermograph, is very nearly proportional to the intensity of the solar radiation falling on a blackened surface normal to the ray, as measured by the pyrheliometer. In other words, the scale is linear and the loss of energy conforms to Newton's law of cooling. While the telethermograph includes the sky radiation as well, the apparatus can be calibrated in terms of the solar radiation on bright days, since on clear days the ratio of sun to sky radiation appears to be fairly constant and the latter at the elevation of Akron (4,200 feet) is small compared with the direct radiation from the sun. A comparison of the telethermograph with the pyrheliometer, when the former is used for measuring radiation, is given in figure 1.

The radiation data given in this paper are expressed in terms of differential temperatures and the mean values are converted to calories per square centimeter per minute on a surface normal to the sun's rays.[1] The radiation is integrated for hourly periods so that zero radiation is not recorded until the hour following the hour interval during which the sun set, or preceding the hour interval during which the sun rose.

[1] The magnification of the differential sunshine instruments was not the same in 1912 and 1914. To convert to calories per square centimeter per minute multiply the differential temperatures in the 1912 observations by 0.0335; and in the 1914 observations by 0.028. In the 1914 observations the instruments were so adjusted as to give differential temperatures in degrees Fahrenheit.

WET-BULB DEPRESSION.—The measurement of the depression of the wet bulb was automatically carried on by means of a second differential telethermograph. One bulb was surrounded by muslin which was kept continuously saturated with water by means of a slowly-dripping Mariotte apparatus. In these measurements both bulbs were inside the instrument shelter and protected from solar radiation. The apparatus thus measured the depression of the wet bulb corresponding to the ventilation afforded by the wind through the shelter, which was similar to that to which the plants were subjected.

EVAPORATION.—In measuring the evaporation a shallow copper tank 91.3 cm. (3 feet) in diameter and 2.5 cm. deep was used, being mounted on the platform of an automatic scale of the type used in the transpiration measurements. The tank was clamped to a heavy, flat, wooden base,

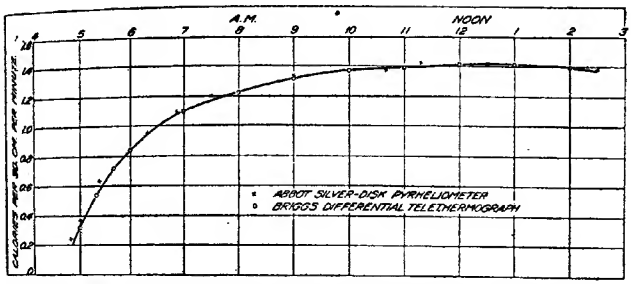

FIG. 1.—Curve showing the comparison of the readings of the differential telethermograph with those of Abbot's silver-disk pyrheliometer.

which was supported on leveling legs about 3 feet above the scale platform (Pl. LV, fig. 3). The inside of the tank was blackened with a mixture of lampblack in "bronzing liquid." The depth of the water in the tank was maintained at approximately 1 cm. by means of a Mariotte apparatus supported from the scale platform and located on the north side of the tank, so that its shadow did not fall on the tank.

AIR TEMPERATURE.—The air temperature was measured by a thermograph calibrated with mercurial thermometers and exposed in a standard shelter of the Weather Bureau pattern.

WIND VELOCITY.—The wind velocity was measured automatically by an anemometer of the Weather Bureau pattern, located 3 feet above the ground. In the 1914 measurements these measurements were supplemented by a special instrument recording each one-twentieth of a mile.

TRANSPIRATION RATE ON CLEAR DAYS IN RELATION TO PHYSICAL FACTORS

The transpiration graph for a single pot of plants for a single day usually shows slight irregularities. In order, therefore, to determine whether such departures are normal or accidental, it is necessary to combine

the transpiration graphs for a number of clear days sufficient to eliminate or minimize the accidental features. In the same manner a composite graph for the corresponding days can be prepared for each of the cyclic environmental factors—radiation, temperature, and wet-bulb depression. The evaporation data have also been combined in the same way. This procedure is not adapted to factors which are essentially noncyclic in character. Wind velocity, for example, is essentially cyclic in some regions and noncyclic in others. While the wind at Akron gives evidence of a daily periodicity, the cyclic character is not sufficiently developed to give the composite graph much weight. The discussion is not, however, limited to the composite values, the hourly values of the transpiration and of each environmental factor being given in the tables for each day considered.

WHEAT

The data obtained for the transpiration of wheat (*Triticum* spp.) on clear days in 1912 are given in Table I, and the environmental data for the corresponding period, including solar radiation, air temperature, and wind velocity in Tables II, III, and IV, respectively.

TABLE I.—*Transpiration rate (in grams per hour) of wheat, at Akron, Colo., during June and July, 1912*

Variety.	Balance No.	Date.	Hour ending— A.M.											Noon.	P.M.											
			1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	B	June 25	6	6	6	8	10	20	80	140	180	220	240	240	240	240	270	240	220	180	94	30	12	12	10	10
Do.	B	26	16	12	12	14	16	60	110	140	140	170	170	200	220	210	250	240	200	180	74	14	12	14	12	12
Do.	B	27	20	14	8	6	16	20	140	200	240	240	250	260	260	260	270	250	200	190	46	26	26	14	10	10
Do.	B	28	10	8	8	8	8	20	110	140	210	270	270	260	280	320	310	290	240	160	70	20	20	30	16	12
Do.	B	July 5	6	6	12	12	12	20	60	130	150	170	180	180	180	180	170	170	140	120	60	22	20	12	12	12
Do.	B	7	14	4	4	4	4	40	60	140	160	180	170	180	200	220	240	220	190	140	70	20	20	20	20	20
Do.	B	11	20	16	12	14	2	50	60	160	220	220	240	280	280	300	300	260	240	200	100	40	12	20	20	20
Average for Turkey			13.1	9.4	8.9	9.4	9.7	32.8	88.5	150	186	210	217	229	237	247	258	239	204	167	73.4	24.5	17.4	17.4	14.3	13.7
Kubanka	A	June 25	4	4	4	4	4	20	40	60	90	100	120	120	120	140	140	130	110	90	40	6	6	4	4	4
Do.	A	26	4	4	4	4	4	40	56	86	84	100	110	110	120	120	130	120	110	94	46	4	4	4	4	4
Do.	A	27	4	4	4	4	4	40	80	90	110	100	110	120	140	130	140	120	110	80	20	12	2	2	2	2
Do.	A	28	4	4	4	4	4	20	50	90	100	130	120	140	150	130	160	160	160	100	50	10	10	4	4	4
Do.	A	29	4	4	4	4	4	70	90	120	140	140	140	160	170	170	150	140	130	80	30	14	4	4	4	4
Do.	A	July 5	4	4	4	4	10	32	50	80	120	130	130	140	150	160	160	150	140	100	50	14	4	4	4	4
Do.	A	7	3	3	3	3	4	24	60	120	170	160	180	180	200	220	250	200	180	140	50	16	12	6	6	6
Do.	A	8	8	8	8	6	6	30	100	140	170	190	220	220	250	250	260	260	250	200	110	16	10	10	10	10
Average for Kubanka			4.4	4 4	4.4	4.1	5	34.5	65.7	98.2	123	131	141	149	162.5	165	174	160	149	110.5	49.5	11.5	6.5	4.8	4.8	4.8
Kharkov	C	June 20	4	4	4	4	4	26	60	140	180	240	240	250	270	290	260	260	220	170	80	16	12	12	12	10
Do.	C	27	18	14	12	12	26	70	180	320	280	290	300	280	280	300	280	310	290	200	50	30	6	14	10	8
Do.	C	July 7	16	12	8	6	8	12	80	160	180	230	200	240	230	280	300	280	230	180	114	30	30	30	30	30
Do.	D	June 28	10	10	10	10	14	40	150	220	270	320	330	350	420	420	420	450	390	240	120	30	20	28	26	18
Do.	D	July 2	4	4	4	4	10	30	120	160	200	230	240	280	280	320	360	340	250	190	70	24	10	10	12	10
Do.	D	5	5	5	5	5	12	36	60	160	190	230	220	210	210	200	180	170	140	116	70	26	14	14	14	14
Average for Kharkov			9.5	8.2	7.2	6.8	12.3	35.7	108.3	193.4	217	257	255	268	282	302	300	302	253	183	84	26	15.3	18	17.3	15
Average, all varieties			8.8	7.1	6.7	6.7	8.7	34.3	85.5	142.7	170.7	193.3	199	209.5	221.4	231.4	238.1	226.7	192.3	150	67.3	20	12.7	12.8	11.5	10.6
Percentage of maximum			4	3	3	3	4	14	36	60	71	81	84	88	93	97	100	95	81	63	28	8	5	5	5	4

TABLE II.—*Hourly solar radiation intensity (observed differential temperatures) during wheat transpiration period, at Akron, Colo., during June and July, 1912*

Date.	Weight.	Hour ending— A. M.							Noon.	P. M.						
		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
June 20	1	5	7	13	16	19	21	21	21	21.5	20	17	14	10	7	0
25	2	5	10	15	19	21	23	24	25	24	24	23	20	11	10	2
26	2	2	10	16	20	21	23.5	23.5	25	25.5	25.5	24.5	21	18	6	0
27	3	1	10	15.5	18.5	20	21.5	24	25	24	23	23.5	20	15	9	0
28	3	0	8	16	18	21	24	25	25.5	26	26	24	19.5	15	6	2
29	1	3.5	10	15.5	18	20.5	21.5	22	22	22	21.5	20	14	6	1	0
July 2	1	4	10	16	18	21.5	23	23.5	23.5	23	22.5	21	14	7	9	0
5	3	1	5	15	19	21	22	23.5	23.5	23	22.5	20	17	13	9	1
7	3	0	9	15	18	22	24	24	23.5	24	22.5	22.5	15	13	6	0
8	1	0	9	17	18.5	19.5	21	22	22.5	23	21	19.5	18	13.5	8	3.5
11	1	0	10	15	18	20	21	21.5	22	21	10	11	4	5	6	0
Average	....	1.6	8.7	15.4	18.4	20.8	22.6	23.6	24.0	23.8	22.7	21.6	17.2	12.7	7.3	.8
Calories per square centimeter per minute	....	.05	.29	.52	.62	.70	.75	.79	.80	.80	.76	.72	.58	.43	.24	.03
Percentage of maximum	....	7	36	64	77	87	94	98	100	99	95	90	72	53	30	3

TABLE III.—*Hourly temperatures (in degrees Fahrenheit) during wheat transpiration period, at Akron, Colo., during June and July, 1912*

Date.	Weight.	Hour ending— A. M. 1	A. M. 2	A. M. 3	A. M. 4	A. M. 5	A. M. 6	A. M. 7	A. M. 8	A. M. 9	A. M. 10	A. M. 11	Noon. 12	P. M. 1	P. M. 2	P. M. 3	P. M. 4	P. M. 5	P. M. 6	P. M. 7	P. M. 8	P. M. 9	P. M. 10	P. M. 11	P. M. 12
June 20	1	48.5	48	47.5	48	49	52.5	59	63	68	71	73.5	75	76.5	77	77	77.5	77	75	69	66	61	58	56	55
25	2	59	58	56	55.5	55	57	63	68	74	78	81	83	84	85	85.5	85	84	83	79	70	64	62	61	60.5
26	2	59	58	56.5	56	56	58	65	69	73	78	83	84	85.5	86	86.5	86	85	83.5	77	71	64	62	61	60.5
27	3	61.5	63	62	61	58	59	68	75	79	81.5	83	85	86.5	87.5	88	88	87	85	78	72.5	71	68	65	62
28	3	59	58.5	58	58.5	57.5	58	66	70	76	81	83	85.5	87	88	88.5	88.5	87	84	79	75	70	68.5	69	68
29	1	66	63.5	63	61.5	59	60	64	70	74	78	81	83.5	87	87.5	88.5	88	86	84	79	75	72.5	72.5	71.5	69.5
July 2	1	53.5	52.5	50.5	50	50.5	54	63	67	71	74	77.5	80	82.5	84	84	83.5	80	77.5	73	70.5	68	66	63	62.5
5	3	49	48.5	49.5	49	49	52	55	59	64	68	70	72	74	75	76	76	76.5	75.5	72	67	61	58.5	55	55
7	3	65	63	61	58	55	58	68	72.5	77	80	83	86	89	91	90	88	87	85	79	73	75	77	71	68
8	1	61	60	59	60	60.5	62	69	77	82	86	90.5	92.5	93.5	95.5	96	95.5	94	92	84	77	68	64	64	63.5
11	1	64	63	61.5	61	61	62.5	66	70	77	81	84	86	89	96	91.5	91	87	81.5	76	71.5	67	63.5	61.5	62
Average		58.7	58	57	56.3	55.5	57.2	64.2	69.1	74.0	77.8	80.6	82.7	84.6	85.8	86.1	85.7	84.4	82.5	77.0	71.6	67.8	66.1	63.8	62.6
Average in degrees centigrade		14.8	14.4	13.9	13.5	13.1	14.0	17.9	20.6	23.3	25.4	27.0	28.2	29.2	29.9	30.1	29.8	29.1	28.1	25.0	22.0	19.9	18.9	17.7	17.0
Percentage of maximum range		10	8	5	3	0	6	28	44	60	73	82	89	95	99	100	99	94	88	70	53	40	35	27	23

TABLE IV.—*Wind velocity in miles per hour during wheat transpiration period at Akron, Colo., during June and July, 1912*

Date.	Weight.	Hour ending— A. M. 1	2	3	4	5	6	7	8	9	10	11	Noon. 12	P. M. 1	2	3	4	5	6	7	8	9	10	11	12
June 20	1	......	......	......	......	......	......	......	5	4	3	3.8	3	2.7	2.7	3.1	2.4	1.5	7.6	2	1	1.5	0.8	0.2	1.2
25	2	3.0	3.0	2.0	3.0	3.0	3.0	6	7	6	5.5	5.5	4.5	4.5	4.7	5.0	6.0	5.2	2.7	1.5	1.5	1.2	2	3	1
26	2	3.0	2.5	2.0	4.0	5.0	4	7.2	9.5	5	4.2	2.9	3.0	1.5	1.5	1.3	2.3	3.9	4.1	2.0	1.5	1.5	1	4	4
27	3	4.0	6.0	5.2	4.0	3.5	4.5	5.5	8.6	10.8	13.2	12.8	12.6	10.7	10	9	9.2	5.6	7.5	7.0	4.0	3.0	2.0	3.0	4.0
28	3	1.0	2.5	3.0	3.5	3.0	5.0	......	4.3	4.5	4.6	3.2	3.0	5.5	7.0	6.2	6.7	6.0	4.0	1.5	1.5	1.0	2.0	......	......
29	1	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
July 2	1	1.0	1.0	.5	.5	.5	.5	4.2	6.0	3.8	5.3	2.8	3.0	4.0	4.3	4.0	4.5	7.0	10.5	1.0	7.0	4.0	5.0	2.0	4.0
5	3	1.0	4.0	2.5	1.5	5.0	5.0	......	8.0	8.5	8.0	7.7	7.3	7.0	6.0	4.0	3.7	2.5	2.0	1.5	.5	1.0	.5	.5	1.0
7	3	8.5	5.0	5.0	1.5	1.5	2.0	4.3	10.0	9.0	6.5	4.0	3.0	2.7	3.1	6.0	8.0	8.0	7.1	3.0	.5	1.5	3.0	2.0	2.0
8	1	2.0	2.0	5	6.0	6.0	4.0	4.7	4.0	5.0	5.5	7.5	5.2	3.4	5.5	6.3	4.0	6.2	5.5	3.5	1.5	1.0	1.5	2.0	1.5
11	1	5.0	4.5	7.5	6.0	7.0	9.0	9.3	8.3	5.7	3.7	3.0	2.4	2.2	2.6	2.0	2.9	7.5	12.0	4.0	1.0	0.7	0.3	1.5	4.0
Average		3.3	3.7	3.6	3.1	3.6	4.1	5.7	7.5	7.0	6.7	5.9	5.3	5.1	5.3	5.2	5.7	5.3	5.3	2.8	1.8	1.6	1.8	2.1	2.5

The mean values are plotted in figure 2. It should be recalled that all transpiration measurements in 1912 were made in the hail-screen inclosure (Pl. LIV, fig. 1). The radiation measurements were likewise made under this screen, which reduced the radiation about 20 per cent (Briggs and Shantz, 1914, p. 3). It should also be borne in mind that during the year of 1912 the solar radiation outside the inclosure was about 20 per cent. lower than normal (Briggs and Shantz, 1914, p. 54).

The mean solar radiation shown in the first curve of figure 2 is relatively symmetrical, as would be expected if clear or only slightly cloudy days

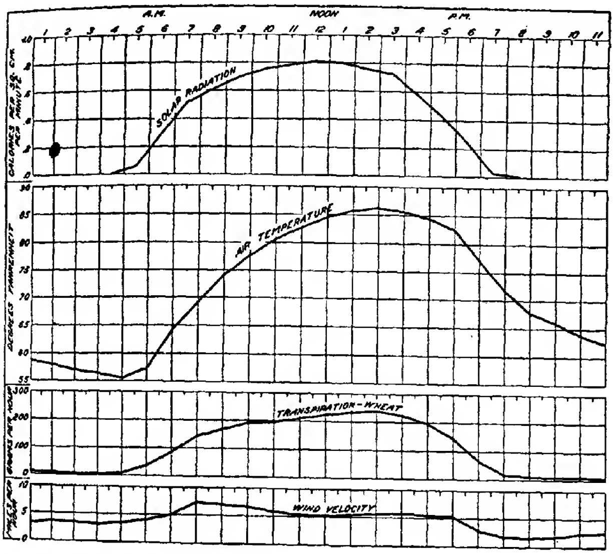

FIG. 2.—Composite transpiration graph of wheat and environmental graphs for corresponding period.

are chosen. The maximum radiation is reached at 12 o'clock, noon, and amounts at that time to only 0.80 calories per square centimeter per minute. The gradient is steep during the early morning and late afternoon, but there is little change in the radiation intensity during the midday hours.

The second graph in figure 2 gives the hourly air temperature in degrees Fahrenheit. The temperature reaches its minimum, 55° F., between 4 and 5 a. m., and its maximum, 86° F., between 2 and 3 in the afternoon. The average temperature from noon to midnight is much higher than from midnight to noon.

The transpiration is recorded in grams per hour. It will be seen from the graph in figure 3 that the transpiration during the night is almost negligible. A marked increase is recorded at 6 o'clock in the morning.

The maximum of 238 gm. per hour is reached about 2.30 p. m., after which the transpiration falls rapidly and acquires the average night rate soon after sunset. There is an indication from the flattening of the curve after 8 o'clock a. m. that from this point on to the maximum the plant modifies its transpiration coefficient.[1] This may be in part due to the closing of the stomata during this period and in part to the lowering of the vapor pressure of the sap of the mesophyll cells resulting from an increase in concentration.

At the bottom of figure 2 is shown the mean wind velocity for each hour of the day. It will be seen that the maximum rate is reached about 7.30 a. m. There is a gradual falling off until about noon, after which the wind velocity remains constant until 5.30 p. m. During the night the rate is somewhat lower.

The transpiration graph of wheat in figure 2 is a composite based upon transpiration measurements of Kharkov and Turkey winter wheats, both

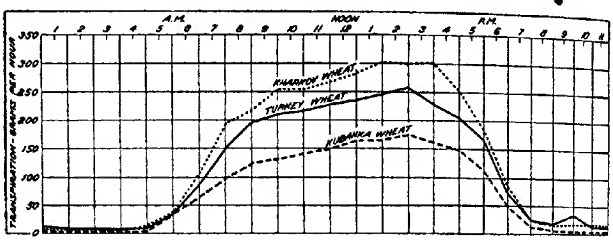

FIG. 3.—Composite transpiration graphs for the three varieties of wheat from which the composite graph of figure 2 was obtained.

being varieties of *Triticum aestivum*, and of one hard spring wheat, Kubanka, a variety of *Triticum durum*.[2] The transpiration graphs for each variety, based upon the data given in Table I, are presented in figure 3. It will be noted that the graphs have essentially the same form and that each graph after 9 a. m. shows a falling off in the transpiration rate below that indicated by the slope during the early morning hours.

OATS[3]

The data covering the transpiration measurements of oats (*Avena sativa*) on clear days are presented in Table V and the environmental measurements for the corresponding period in Tables VI to IX. The

[1] If a plant in its transpiration response to its environment acted as a free physical system, it would be possible to express the transpiration rate in the form of an equation involving the intensity of each of the individual environmental factors. If the relative part played by each factor in determining transpiration were known, then simply by determining the transpiration rate corresponding to some given environment, the transpiration rate for any other environment could be computed. The ratio of the transpiration rate to the environmental intensity would then be defined as the *transpiration coefficient* of the particular plant under observation.

[2] Kharkov, C. I. (Cereal Investigations) No. 1583; Turkey, C. I. No. 1571; and Kubanka, C. I. No. 1440.

[3] Swedish Select, C. I. No. 134.

mean hourly values for each environmental factor and for the transpiration are plotted in figure 4. The graphs for the physical factors represent in each case the mean hourly values for eight clear days. The

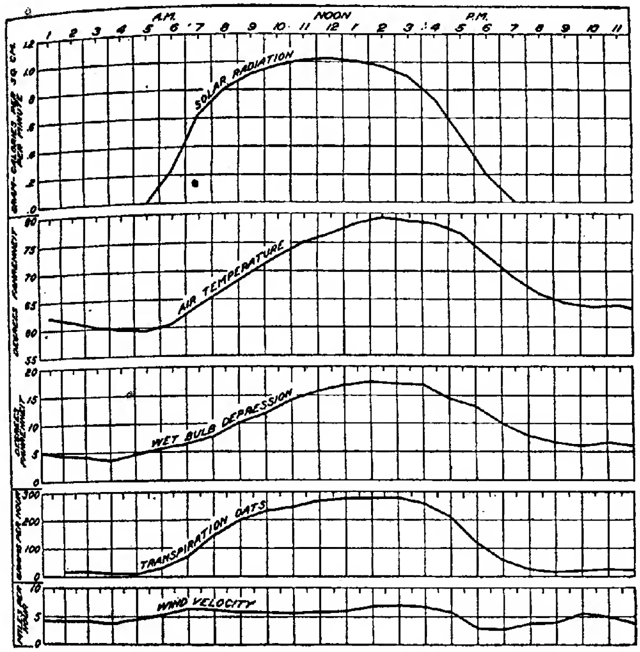

FIG. 4.—Composite transpiration graph for oats, with environmental graphs for corresponding period.

transpiration measurements were made in duplicate, using two pots of oats of the same variety, each pot being mounted independently on an automatic balance. The hourly transpiration values plotted in figure 4, therefore, represent the mean of 16 determinations.

TABLE V.—*Transpiration rate (in grams per hour) of oats at Akron, Colo., from August 4 to 18, 1912*

Date.	Balance No.	Hour ending—																							
		A. M.											Noon.	P. M.											
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Aug. 4	C	33.2	4	8	8	12	20	50	134	276	314	374	406	400	380	300	220	144	62	28	14	10	24	28	58
	D	36	3	6	6	6	12	36	114	272	316	362	394	464	324	280	214	150	62	32	12	10	20	20	56
5	C	6	4.2	4.2	4.4	4.4	3	92	130	200	202	200	250	296	330	344	330	287	190	52	18	10	8	46	8
	D	6	14.6	6	6	8.4	22	114	146	194	216	220	266	325	340	348	334	280	186	54	20	24	10	45.4	6
8	C	8	......	......	......	......	......	66	144	168	202	190	210	180	180	202	198	164	126	42	16	14	18	10	12
	D	6	......	......	......	......	......	......	132	146	242	192	180	164	166	224	248	170	134	48	18	16	14	10	8
9	C	......	8	6	6	6	......	46	136	136	218	240	236	260	260	264	236	230	180	62	12	6	6	......	......
	D	......	6	6	6	8	10	54	144	200	224	236	280	294	284	300	264	216	174	72	14	8	6	6	4
11	C	46	22	48	4	4	6	6	62	244	250	270	296	300	340	340	340	300	216	96	32	22	20	24	32
	D	44	34	34	34	36	48	110	170	280	280	304	316	276	304	344	356	316	236	96	38	22	20	22	30
12	C	10	36	34	26	18	48	110	198	220	250	244	274	264	296	282	276	230	196	72	18	44	18	18	12
	D	14	40	34	26	26	50	122	238	264	276	320	306	294	330	310	296	252	200	74	24	38	18	14	26
13	C	......	22	10	12	8	2	44	120	164	232	248	250	236	276	258	254	156	54	14	24	......	......	......	......
	D	......	14	12	12	8	8	8	76	186	240	276	300	240	220	246	222	182	136	34	20	......	......	......	......
16	C	4	......	......	......	......	......	......	138	140	172	188	204	200	210	208	198	174	124	48	18	6	4	4	4
	D	3.2	......	......	......	......	......	......	158	178	190	194	240	236	254	258	224	186	140	48	20	14.2	3.4	3.4	3.4
18	C	16	......	......	......	......	......	......	......	92	124	136	154	164	168	180	168	158	106	44	16	12	26	24	18
	D	12	......	......	......	......	......	......	......	100	150	158	176	178	182	190	186	162	112	48	20	10	48	22	16
Average	......	17.5	17.3	17.3	12.5	12.1	20.8	66.0	140	195	227.7	242	263	265.1	269.1	271	253.6	208.7	146.3	53.6	19.6	16.6	16.5	19.8	19.6
Percentage of maximum	......	6	6	6	5	4	8	24	52	72	84	89	97	98	99	100	94	77	54	20	7	6	6	7	7

TABLE VI.—*Hourly solar radiation intensity (observed differential temperature) during oats transpiration period, at Akron, Colo., from August 4 to 18, 1912*

Date.	Hour ending— A. M. 6	7	8	9	10	11	Noon. 12	P. M. 1	2	3	4	5	6
Aug. 4	....	....	22.5	27.5	29	30	30	30	28.5	27	23	7	2
5	7	17	22	26	27	28	29	28.5	28	26	21.5	17	8
9	7	20	25	28	29.5	30.5	31	30	28.5	26	21.5	18	8.5
11	4	17	23	27	29	30	31	30	29	24	19.5	13	2
12	5	16	22	25	27	28.5	27	28	28.5	26.5	22.5	18	9
13	7	22	25	27	29	30	31	30.5	29	27	21	3	—1
16	7	20	25	27	29	30.5	31	30	29	30	22	17	8.5
18	9	17	25	28	20.5	31	31.5	31	29	27	21.5	17	8
Average	6.6	18.4	23.7	26.9	27.5	29.8	30.2	29.7	28.7	26.7	21.5	13.8	5.6
Calories per sq. cm. per minute	.22	.62	.79	.90	.92	1.00	1.01	1.00	.96	.89	.72	.46	.19
Percentage of maximum	22	61	78	89	91	99	100	98	95	88	71	46	19

TABLE VII.—*Hourly temperatures (in degrees Fahrenheit) during oats transpiration period, at Akron, Colo., from August 4 to 18, 1912*

Date.	Hour ending— A. M. 1	2	3	4	5	6	7	8	9	10	11	Noon. 12	P. M. 1	2	3	4	5	6	7	8	9	10	11	12
Aug. 4	61.5	61.5	61.5	61.8	62	62	64	67.5	70	74	78	80.6	83	84	83	82.5	78	75	72	70	65	65	71	67
5	65	63	60	61.5	62	65	68	70	72	73	75	78	80	81.5	82	81	79	76	70	69	69	67	58	58
8	51.6	51	50	52	52	53	57	59	62	63	66	65	67	68	69	68.5	67	66	61	57	55	55	52	52
9	54	52	51	49.5	51	54	63	67	69	71	72.5	73	76	76	77	76	76	72	65	62	59	57	57	55
11	66	66	64	64	62	62	69	74	77	80	83	84	87	88	88	87	85	80	71	66	62	60	63	69
12	72	70	67	63	63.5	65	71	72	75	78	80	80.5	82	82.5	82	80	79	76	69	65	66	64	65	62
13	60	60	58	57.5	55	59	60	63	71	76	79	82	84	87	85	85	83	78	75	67	64	60	62	58
16	74	74	76	73	72	69	61	61	60	61	61	60	60	60	57	56.5	56.5	52	63	68	71	75	79	81
18	55	54	54	55	54	56	61	66	71	76	79	82	83	84	85	84	83	80	71	68	65	66	64	62
Average	62.1	61.3	60.2	59.7	59.3	60.6	63.8	66.6	69.7	72.4	74.9	76.2	78	79	78.7	78	76.3	72.9	69.6	65.8	64	63.2	63.4	62.7
Average in degrees centigrade	16.7	16.3	15.7	15.4	15.2	15.9	17.7	19.2	20.9	22.4	23.8	24.6	25.6	26.1	25.9	25.6	24.6	22.7	20.9	18.8	17.8	17.3	17.4	17.1
Percentage of maximum range	14	10	5	2	0	7	23	37	53	66	79	86	95	100	98	95	86	69	52	33	24	20	21	17

TABLE VIII.—*Hourly wet-bulb depression (in degrees Fahrenheit) during oats transpiration period at Akron, Colo., from August 4 to 18, 1912*

Date.	Hour ending—																							
	A. M.											Noon.	P. M.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Aug. 4	1	1	1	1	1.5	1.5	2	2	4	6	8	9	10.5	12	12.5	13	13	12	9.5	7	5	4	8	7
5	8	9	7	5	4.5	4.5	4.5	6.5	9	10	10	10.5	12	14	14.5	14.5	13.5	12.5	8	6	4.5	4	6	4
8	.5	0	0	0	0	.5	.5	2	6	8.5	11	13	12.5	12.5	12	11	6	4.5	4	3	2.5	2	2	2
9	1.5	1	1	1.5	7	11	13	14	14	15	15	15.5	15	14.5	13	10	6	4.5	3.5	3	2.5	2	1.5	1.5
11	9	9	8.5	8.5	12	16	17	18	19.5	20	21.5	21	20	19	16	12	10	8	6	6.5	7	10	11	9.5
12	7.5	6.5	7	......	......	......	9	15	18.5	18.5	20	21	20.5	21	20.5	20	19	18	14	11	9	10	8.5	8.5
13	7	6	6	5.5	5.5	5	4.5	5.5	11	14	17	18.5	19.5	20.5	20	19	18	16	11	9	8	5	5.5	6
16	3.5	3.5	3.5	3.5	3	3	3	3	4	6	10	15	20.5	20.5	23	20	20.5	20	16	12	9	7	5	4.5
18	4.5	4.5	4	3.5	3.5	3.5	3	3	5	8	14	17	19	19.5	21	22	22	21	17	12	9	8.5	9	10
Average	4.7	4.5	4.2	3.6	4.6	5.6	0.3	7.7	10.1	11.8	14.1	15.6	16.6	17.1	16.9	15.7	14.2	12.9	9.9	7.7	6.3	5.8	6.3	5.9
Percentage of maximum range	8	7	4	0	7	15	20	30	48	61	78	89	96	100	99	90	79	69	47	30	20	16	20	17
Saturation deficit....inches	0.140	0.125	0.119	0.095	0.131	0.141	0.189	0.220	0.308	0.392	0.461	0.529	0.584	0.602	0.592	0.555	0.488	0.418	0.305	0.217	0.193	0.177	0.196	0.167
Percentage of maximum	23	21	20	16	22	23	31	37	51	65	77	88	97	100	98	92	81	96	51	36	32	29	33	28

TABLE IX.—*Wind velocity (in miles per hour) during oats transpiration period at Akron, Colo., from August 4 to 18, 1912*

Date.	Hour ending—																							
	A. M.											Noon.	P. M.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Aug. 4	10.5	10.2	11.1	7.6	8.3	9.0	7.5	8.0	7.0	7.3	8.5	8.6	8.6	10.2	10.8	10.5	7.8	3.9	7.9	7.2	6.4	8.6	16.5	15.4
5	12.1	7.6	6.1	7.0	6.8	5.9	......	6.2	8.1	7.2	6.6	6.4	5.6	5.7	6.4	6.5	5.4	2.9	2.1	4.4	6.3	13.0	3.2	3.1
8	3.5	3.0	4.4	3.6	5.1	4.5	6.0	5.0	4.2	3.0	3.1	3.5	3.3	4.7	5.0	3.6	4.4	.35	.35	.45	.6	1.3	.3	.3
9	.3	1.05	.0	.0	.0	.0	2.5	2.5	3.0	3.5	3.1	4.7	4.2	5.1	5.4	4.8	5.5	4.4	2.0	1.1	.7	1.4	1.1	3.0
11	4.7	3.9	4.4	7.0	7.8	9.0	8.2	7.2	4.5	4.5	4.8	4.4	5.5	6.5	5.0	2.7	1.4	.6	.85	1.65	2.9	8.0	8.2	5.9
12	3.7	5.4	5.0	......	......	......	......	8.4	9.4	11.0	10.0	10.0	10.0	10.3	9.9	9.8	7.9	3.7	2.2	5.2	5.2	4.5	2.8	1.9
13	2.0	2.6	3.4	2.0	.7	2.2	7.3	6.7	6.1	6.1	6.1	4.7	5.5	8.5	9.1	7.9	6.6	4.4	6.1	9.3	6.0	7.0	3.9	.9
16	1.0	1.1	1.6	2.3	2.9	5.8	5.4	5.2	4.4	4.0	3.4	3.2	3.3	3.3	3.6	6.1	5.4	2.9	1.1	1.9	2.0	1.9	.5	.7
18	.2	1.9	1.0	.9	3.6	4.7	......	5.1	3.8	2.8	2.9	3.8	5.1	5.3	5.1	5.9	5.5	2.1	.3	.3	2.5	.9	5.5	2.6
Average	4.2	4.1	4.1	3.4	4.4	5.1	6.2	6.0	5.6	5.5	5.4	5.5	5.7	6.6	6.7	6.4	5.5	2.8	2.5	3.5	3.6	5.2	4.7	3.8

The smoothness of the graphs obtained by this method of composites is in evidence in figure 4. The radiation curve is again seen to be symmetrical with reference to the noon hour and to decrease in either direction, at first slowly and then rapidly, to zero, a type of curve characteristic of clear days. The air temperature, wet-bulb depression, and transpiration all reach their maximum about two hours later. The transpiration graph for oats, like that for wheat, gives evidence of a slight depression or undue flattening after 9 a. m. In other words, one would expect from the corresponding slopes of the radiation and temperature curves that the transpiration graph would be more convex through the period from 9 a. m. to 2 p. m., provided the oat plant responds as a free physical system. It will be noted that the transpiration rate also falls off more rapidly in the afternoon than does the air temperature or the wet-bulb depression. In this respect the transpiration graph corresponds rather strikingly with the solar-radiation and wind-velocity graphs. The increase in wind velocity during the night does not, however, produce a corresponding increase in transpiration. This point will be referred to again. Finally, it is of interest to note that the transpiration loss of oats under Akron conditions during the night hours is extremely small, compared with the loss during the day.

SORGHUM

The sorghum transpiration measurements, like those made with wheat and oats, were conducted inside the screened inclosure and include three varieties of *Andropogon sorghum*—namely, Minnesota Amber, milo, and Dwarf milo[1] (Table X).

The environmental measurements for the corresponding period are given in Tables XI to XIV, inclusive.

[1] Minnesota Amber, A. D. I. 341-13; milo, S. P. I. No. 24960; Dwarf milo, S. P. I. No. 24970.

TABLE X.—*Transpiration rate (in grams per hour) of sorghum, at Akron, Colo., from August 23 to 29, 1912*

Variety.	Balance No.	Date.	Hour ending— A. M. 1	2	3	4	5	6	7	8	9	10	11	Noon. 12	P. M. 1	2	3	4	5	6	7	8	9	10	11	12
Minnesota Amber	B	Aug. 23	10	10	10	10	10	10	72	170	220	340	400	420	460	440	400	340	320	120	54	34	20	20	20	14
Do	B	24	14	20	20	16	14	24	156	242	320	340	430	500	500	420	370	240	136	38	20	22	20	18	22	....
Do	B	25	22	20	20	20	18	28	80	120	200	150	216	160	210	264	260	230	110	28	28	32	28	24	16	20
Do	B	26	20	14	14	14	14	20	60	150	230	294	374	374	352	392	340	310	190	114	28	18	10	10	4	4
Do	B	27	4	4	4	4	12	30	100	180	210	460	440	500	520	530	470	370	244	136	54	40	34	20	20	20
Do	B	28	....	....	....	....	....	....	......	176	232	266	310	360	384	396	386	340	226	140	46	22	22	12	12	10
Do	B	29	10	10	....	....	....	....	56	108	212	324	392	436	456	434	380	296	192	78	44	34	14	24	22	12
Milo	C	25	18	18	18	10	14	16	100	140	180	280	......	......	400	440	480	400	320	130	36	26	28	26	22	20
Do	C	26	16	14	14	14	14	40	100	134	226	288	366	380	410	386	344	310	186	96	22	14	2	2	2	2
Do	C	27	2	2	2	2	2	36	100	180	240	360	380	520	520	510	460	350	310	90	46	32	30	20	18	16
Do	C	28	12	12	10	10	10	10	70	170	190	230	274	324	380	364	334	292	216	120	26	20	14	8	8	10
Do	C	29	12	4	4	4	4	4	32	200	210	280	300	360	440	440	390	370	270	50	36	40	16	18	12	4
Dwarf milo	D	24	16	14	14	14	10	16	52	110	150	210	250	......	......	340	300	260	210	110	20	14	12	12	10	16
Do	D	25	16	10	10	10	10	10	36	114	160	234	284	354	336	336	300	260	214	100	18	18	20	24	20	14
Do	D	27	2	2	2	2	2	8	50	130	190	260	320	340	380	400	332	264	186	70	44	30	24	20	14	12
Do	D	29	....	....	....	....	....	....	20	80	130	200	300	320	330	340	320	300	220	90	40	24	22	....	....	....
Average	......	....	12	11	11	10	10	20	72	150	206	282	336	382	405	402	368	307	222	94	35	26	20	17	15	12
Percentage of maximum	......	....	3	3	3	2	2	5	18	37	51	69	83	94	100	99	91	76	55	23	9	6	5	4	4	3

TABLE XI.—*Hourly solar radiation intensity (differential temperatures) during sorghum transpiration period, at Akron, Colo., from August 23 to 29, 1912*

Date.	Weight.	Hour ending— A. M. 6	7	8	9	10	11	Noon. 12	P. M. 1	2	3	4	5	6
Aug. 23	1	6	19	25	26	28	29	29.5	29.5	27.5	25	20	18	3
24	2	5	14	24	26.5	29	30	31	31	31	27	24	19	10
25	3	7	17	24	27	28.5	30	31	31	30.5	28	23	19	6
26	2	6	17	23	26	28.5	30	31	30.5	28	26	20	14	4
27	3	8	14	23	27	29.5	31	32	32	31	25	18	11	5
28	2	9	16	22	24.5	26.5	29	30.5	30	28.5	26	21	16	9
29	3	4	21	25	27.5	30.5	32	33	33	31.5	29	24	19	2
Average	......	6.5	16.8	23.7	26.5	29	30.4	31.4	31.2	30.1	27	21.6	16.4	5.5
Calories per sq. cm. per minute	......	.22	.56	.79	.89	.97	1.02	1.05	1.05	1.01	.90	.72	.56	.18
Percentage of maximum	......	21	54	75	84	92	97	100	99	96	86	69	53	18

TABLE XII.—*Hourly temperatures (in degrees Fahrenheit) during sorghum transpiration period, at Akron, Colo., from August 23 to 29, 1912*[1]

Date.	Weight.	Hour ending— A. M. 1	2	3	4	5	6	7	8	9	10	11	Noon. 12	P. M. 1	2	3	4	5	6	7	8	9	10	11	12
Aug. 23	1	57	56	55	57	55	60	68	73	78	82	86	89	90	90	91	90	86	80	74	70	64	61	63	65
24	2	63	60	59	57	56	63	68	72	76	81	85	87	88	89	87	87	84	76	68	66	65	60	65	66
25	3	70	65	58	60	60	64	73	75	80	87	91	93	94	94	95	92	89	80	74	73	75	71	67	66
26	2	60	62	63	61	60	67	69	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average	....	64	61.9	59.1	59.1	58.4	64	70.1	73.7	78.3	84.1	88.1	90.3	91.3	91.7	91.7	90	86.8	78.7	72	70.2	69.8	65.7	65.7	65.8
Average in degrees centigrade	....	17.8	16.6	15.1	15.1	14.7	17.8	21.2	23.2	25.7	28.9	31.2	32.4	32.9	33.2	33.2	32.2	30.4	25.9	22.2	21.2	21	18.7	18.7	18.8
Percentage of maximum range	....	17	11	2	2	0	17	35	46	60	77	89	96	99	100	100	95	85	61	41	35	34	22	22	22

[1] The thermograph record for this period is incomplete, but the days for which no record is given were similar in character to those recorded, as shown by the following maximum and minimum temperatures:

	Maximum. °F.	Minimum. °F.
Aug. 23	92	56
24	90	57
25	95	60
26	90	53
Aug. 27	96	57
28	89	58
29	96	55

TABLE XIII.—*Hourly wet-bulb depression (in degrees Fahrenheit) during sorghum transpiration period, at Akron, Colo., from August 23 to 29, 1912*

Date.	Weight.	Hour ending— A. M. 1	2	3	4	5	6	7	8	9	10	11	Noon. 12	P. M. 1	2	3	4	5	6	7	8	9	10	11	12
Aug. 23	1	5.5	5	5	4.5	4	4	4.5	4.5	9	13	16	17	19	20.5	22	23	25	26	22	18.5	16.5	13	11	10
24	2	10.5	11.5	12	10.5	9	8.5	8.5	10	14	17	20	23	27	28	28.5	28	27	25	22	18	13	11.5	11	10
25	3	11	11.5	12	11	9	8	7.5	8.5	16	19.5	23	27	31	31	31.5	30.5	31	31	23	17	16	16	17	16
26	2	13	12	10.5	10	11	11	11.5	14	19	22	25	25	24.5	24.5	22	21.5	19	17	12	9	6	5.5	4.5	3.5
27	3	2.5	1.5	1.5	3	4	4	8	12	16	19	23	26	27	27	27	27.5	26	26	21	16.5	14	14.5	14	11
28	2	8.5	7	5.5	5	5	5	6	10	15	18	20	22	23	23.5	23.5	24	22	20.5	18	14	10	9	7	5.5
29	3	5	5	4.5	3.5	2.5	1.5	1	1	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Average		7.8	7.5	7.2	6.7	6.3	5.8	6.6	8.6	15.5	19.1	21.9	24.3	26.3	26.7	26.6	26.5	25.5	24.8	19.8	15.5	12.7	12.0	11.5	9.9
Percentage of maximum range		10	8	7	4	2	0	4	13	46	64	77	89	98	100	100	99	94	91	67	46	33	30	27	20
Saturation deficit, inches		0.222	0.206	0.179	0.167	0.179	0.178	0.218	0.294	0.565	0.750	0.909	1.020	1.107	1.138	1.138	1.110	1.004	0.815	0.576	0.471	0.393	0.333	0.321	0.287
Percentage of maximum		19	18	16	15	16	16	19	26	50	66	80	90	97	100	100	98	88	72	51	41	35	29	28	25

TABLE XIV.—*Wind velocity (in miles per hour) during sorghum transpiration period, at Akron, Colo., from August 23 to 29, 1912*

Date.	Weight.	Hour ending— A. M. 5	6	7	8	9	10	11	Noon. 12	P. M. 1	2	3	4	5	6	7	8
Aug. 23	1	5.0	5.3	7.6	10.3	8.9	8.3	7.4	6.1	5.7	5.4	6.2	5.8	5.4	1.0	1.3	1.1
24	2	5.4	5.3	6.7	8.3	8.2	6.7	8.1	8.2	7.3	4.5	3.9	3.4	5.0	3.9	.9	.5
25	3	6.2	5.6	7.1	10.1	10.0	8.5	8.7	7.1	5.1	6.1	3.4	6.1	5.0	1.2	.3	.5
26	2	6.7	7.2	7.0	3.8	4.1	3.5	4.6	4.6	6.5	7.2	9.6	9.4	9.8	5.8	3.0	2.5
27	3	1.3	6.0	7.0	9.0	9.8	10.2	10.8	10.7	10.0	10.0	9.4	6.6	6.5	10.5	5.8	3.4
28	2	3.5	4.5	5.3	6.9	2.3	10.3	8.4	7.3	5.4	4.9	5.4	6.1	6.0	5.7	2.4	1.4
29	3	2.5	3.8	3.0	7.2	9.8	9.4	10.6	10.2	10.6	7.7	7.1	8.7	9.2	8.5	4.6	5.7
Average	......	4.1	5.3	6.1	8.0	7.9	8.4	8.7	8.1	7.6	6.9	6.5	6.7	6.8	5.8	2.9	2.4

The sorghum measurements were made during the latter part and the oat measurements during the first part of August. The amplitude and spread of the radiation curves for the two periods are essentially the same (see figs. 4 and 5). The air temperature during the sorghum period was, however, much higher, the average daily maximum being over 91° F.,

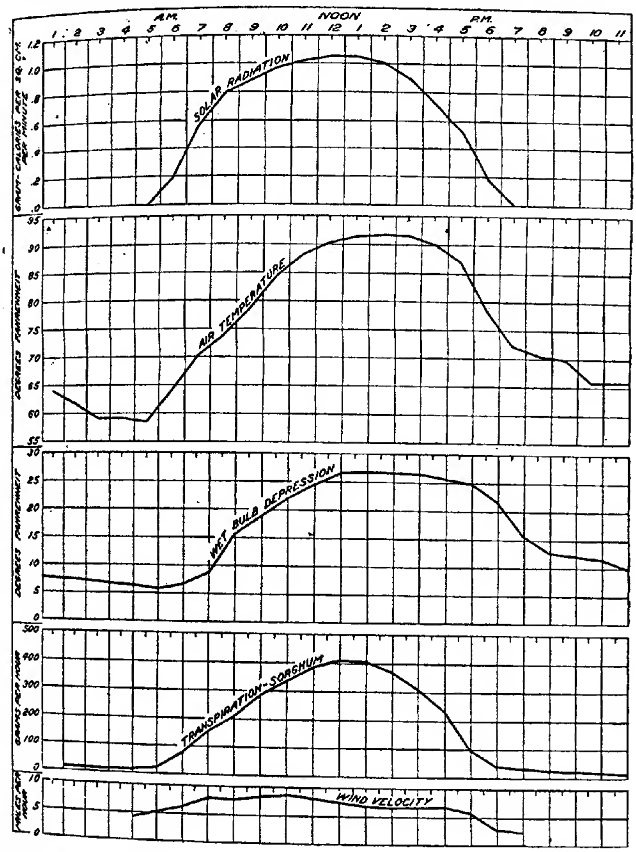

Fig. 5.—Composite transpiration graph of sorghum, with environmental graphs for corresponding period.

compared with a maximum of 79° during the oat period. There is also a corresponding difference in the wet-bulb depression, the mean maximum depression during the sorghum period being over 26°, compared with 17° during the oat period. The conditions were consequently more severe during the sorghum period—i. e., such as to induce a higher transpiration rate. Yet it will be seen, on reference to the transpiration graph

in figure 5, that sorghum, even under the more severe conditions imposed, gave no indication of a flattening of the peak of the transpiration curve. Furthermore, the maximum of the sorghum transpiration curve occurs at approximately noon, and the curve is nearly symmetrical. In brief, the transpiration graph of sorghum appears to follow more nearly the radiation curve than either wheat or oats. It is of interest in this connection to note that sorghum is one of the most efficient of the crop plants in the use of water, the sorghum varieties used in these experiments having a water requirement amounting to only 64 per cent of that of the oat plants.[1]

RYE

The transpiration data for rye (*Secale cereale*)[2] on clear days are given in Table XV. These observations were made outside the inclosure, under freely exposed conditions, from June 22 to July 3, 1914. The environmental measurements for this period are given in Tables XVI to XX, inclusive. Hourly evaporation measurements from a free-water surface were also made in 1914, with the aid of an automatic balance. The hourly means for the environmental factors are plotted in figure 6, together with the hourly evaporation and the hourly transpiration of rye, the latter being represented by the mean of 12 automatic records taken on six different days.

[1] Based upon water-requirement measurements of the same plants. (Briggs and Shantz, 1914.)
[2] Spring rye, C. I. No. 73.

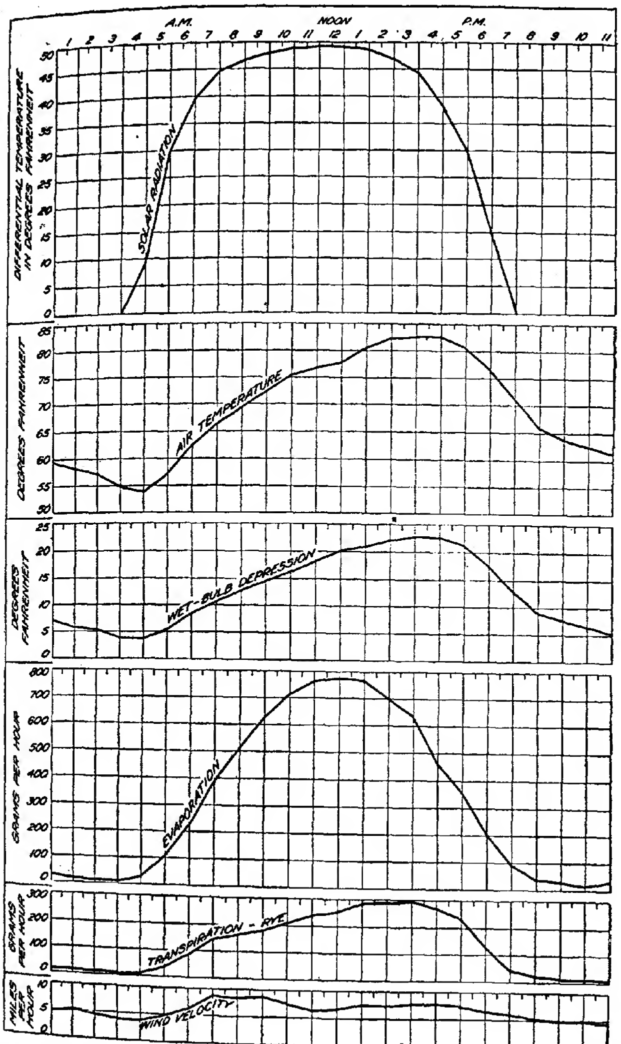

FIG. 6.—Composite transpiration graph of rye, with environmental graphs and evaporation graph for corresponding period.

TABLE XV.—*Transpiration rate (in grams per hour) of rye, at Akron, Colo., during June and July, 1914*

Date.	Balance No.	Hour ending— A. M. 1	2	3	4	5	6	7	8	9	10	11	Noon. 12	P. M. 1	2	3	4	5	6	7	8	9	10	11	12
June 22	A	.....	.....	.....	.....	20	80	140	190	190	220	220	260	260	280	320	300	300	230	70	46	30	16	12	12
22	C	.....	.....	.....	.....	0	100	130	200	210	200	210	230	240	300	300	300	300	260	74	30	10	20	20	10
24	A	30	40	60	0	0	16	66	190	190	180	200	260	320	360	380	400	400	350	210	46	10	10	10	10
24	C	20	30	30	0	0	16	66	140	160	200	200	260	300	320	340	380	360	300	200	60	0	0	0	16
27	A	0	0	0	0	20	20	100	130	160	184	210	200	210	230	240	280	240	240	160	40	30	20	20	20
27	C	16	6	0	0	6	56	100	128	156	184	210	200	200	240	240	260	240	240	148	40	20	20	20	20
29	A	20	0	0	20	10	10	40	100	120	140	180	180	230	290	250	240	240	220	140	40	40	10	10	20
29	C	20	20	16	16	20	20	80	140	140	150	150	240	240	260	280	280	250	250	140	40	20	20	20	10
July 2	A	0	0	0	20	10	26	66	140	190	210	240	260	260	300	260	240	220	140	60	20	.....	.....	.....	.....
2	C	16	20	10	10	20	50	100	150	190	210	240	240	240	280	280	260	200	150	60	20	.....	.....	.....	.....
3	A	.....	.....	.....	.....	6	36	60	100	150	170	260	280	280	280	300	290	250	220	100	60	20	20	10	10
3	C	.....	.....	.....	.....	0	16	60	120	140	200	260	260	260	280	290	290	260	200	120	46	36	20	20	0
Average	....	16	14	14	8	10	38	84	144	166	187	214	240	254	286	290	294	272	234	124	42	22	16	14	12
Percentage of maximum	....	5	5	5	3	3	13	29	49	56	64	73	82	86	97	99	100	93	80	42	14	7	5	5	4

TABLE XVI.—*Hourly solar radiation intensity (differential temperatures in degrees Fahrenheit) during rye transpiration period at Akron, Colo., in June and July, 1914*

Date.	Hour ending— A. M. 5	6	7	8	9	10	11	Noon. 12	P. M. 1	2	3	4	5	6	7
June 22	7	18	39	44	48	49.5	50	50	50	49	47	45	43	37	13
24	12	33	42	46	48	50.5	51	50	48.5	48	46	44	40	34	16
27	9	31	39	44	46	47	48	49	49	48	46	44	39	35	20
29	7	25	38	43	46	47	48	48.5	48.5	48	47	44	41	35	22
July 2	11	30	40	44	45	47	48	48.5	49	49.5	47	42	28	12	3
3	10	28	37	45	47	47	48	48.5	49	48	47	46	37	23	14
Average	9.3	27.5	39.2	44.3	46.7	48.0	48.8	49.1	49.0	48.4	46.7	44.2	38.0	29.3	14.7
Calories per sq. cm. per minute	0.26	0.80	1.10	1.24	1.31	1.34	1.37	1.38	1.37	1.36	1.31	1.24	1.06	0.82	0.41
Percentage of maximum	19	58	80	90	95	97	99	100	100	99	95	90	77	60	30

TABLE XVII.—*Hourly temperatures (in degrees Fahrenheit) during rye transpiration period at Akron, Colo., during June and July, 1914*

Date.	Hour ending— A. M. 1	2	3	4	5	6	7	8	9	10	11	Noon. 12	P. M. 1	2	3	4	5	6	7	8	9	10	11	12
June 22	64	60	60	57.5	56.5	58.5	61.0	65.0	68.0	69.5	71.0	73.0	74.5	76	78	78.5	78.5	75.5	71	66	63.0	63.5	64.0	63
24	61	61	62	59.0	57.5	61.5	67.5	70.5	72.0	74.5	78.5	81.5	83.0	84	86	86	86.5	84.0	78	73	69.0	67.5	64.5	63
27	56	55	54	50.0	49.5	55.0	62.0	65.0	68.5	71.5	75.0	77.0	79.0	81	81.5	82	84.0	82.5	77	68	61.5	59.5	58.5	56
29	58	55	50	48.0	47.5	53.0	59.0	62.0	66.5	70.0	73.0	71.0	79.0	81	81.5	81.5	81.0	79.5	76	71	68	64.0	64.5	64
July 2	57	56.5	56.5	56	56.5	58.5	63.0	67.5	71	73.5	76	78	81	81.5	82	82.5	82	81	79	74	65	62	60	60.5
3	60	61	61	58	56	57	62.5	67	70	75	78.5	80.5	82.5	83	84	84.0	83.5	81.5	77.5	74	69	66	64	61.0
Average	59.3	58.1	57.2	54.8	53.9	57.2	62.5	66.2	69.3	72.3	75.3	76.8	79.8	81.1	82.2	82.4	82.6	80.7	76.4	71.0	65.9	63.8	62.6	61.2
Average in degrees centigrade	15.2	14.5	14.0	12.7	12.2	14.0	16.9	19.0	20.7	22.4	24.1	24.9	26.6	27.3	27.9	28.0	28.1	27.1	24.7	21.7	18.8	17.7	17.0	16.2
Percentage of maximum range	19	15	12	3	0	12	30	43	54	64	75	80	90	95	99	99	100	93	78	60	42	35	30	25

TABLE XVIII.—*Hourly wet-bulb depression (in degrees Fahrenheit) during rye transpiration period at Akron, Colo., in June and July, 1914*

Date.	Hour ending— A. M. 1	2	3	4	5	6	7	8	9	10	11	Noon. 12	P. M. 1	2	3	4	5	6	7	8	9	10	11	12
June 22	......	......	......	......	7	9	9.5	9	11	12	12.5	14	15	16	18	19.5	19.5	19	16	11	7	5	5.5	.5
24	7	4	5	3	1	1.5	4	7.5	8	8	10	13	15	16.5	18.5	21	21.5	19.5	15	10	6	5	3.5	3
27	12	11	10	7	7	9	12	15	17	20	22	23	24.5	25	26.5	27	27	24	18	13	10	9.5	9.5	7.5
29	7	6	5	4	2	3	8	10	12	12	14	17	20	21	22	22.5	22	21	18	16	14	10	7	6
July 2	5	4.5	4	3.5	5	7	10	14	17	18	19	21	23	22	23	23	22	21	18	11	5	5	5	4
3	4	3	3	2	1	3	7	8	12	17	19	21	23	24	24	24	24	23	20	16	12	11	8	7
Average	7.0	5.7	5.4	3.9	3.8	5.4	8.4	10.6	12.8	14.5	16.1	18.2	20.1	20.8	22.0	22.8	22.7	21.2	17.5	12.8	9.0	7.6	6.4	4.7
Percentage of maximum range	17	10	8	1	0	8	24	36	47	56	65	76	86	90	96	100	100	92	73	47	27	20	14	5
Saturation deficit, inches	0.180	0.131	0.135	0.095	0.093	0.134	0.265	0.288	0.367	0.443	0.528	0.586	0.683	0.733	0.788	0.820	0.826	0.724	0.686	0.397	0.249	0.204	0.194	0.123
Percentage of maximum	22	16	16	12	11	16	32	35	44	54	64	71	83	89	95	99	100	88	83	48	30	25	23	15

TABLE XIX.—*Wind velocity (in miles per hour) during rye transpiration period at Akron, Colo., in June and July, 1914*

Date.	Hour ending—																							
	A. M.											Noon.	P. M.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
June 22	1	3	2	3	2	3.8	5	11	9	7	4	3.5	3.8	7	8	11	11	11	8	2	2	4.5	6.5	6.5
24	2	4.5	9.5	6.5	5.5	6.3	5	4.3	6	6.5	5.5	4.5	5.5	6	6	7.5	8	9.5	10	5.6	3.3	2.6	2.3	1.5
27	7.5	8.5	7.0	4.0	3.0	3	4	6.5	8.5	8.0	7.0	4.5	5.5	3.3	3.3	3	2.5	1	2	4.5	3	3	3	1.6
29	5	3	0.3	0.3	0.3	1	5	7	7.5	6.5	7.5	8	8.5	10.5	10	10.5	11	10.5	10	8	8	5	6	8
July 2	6	6	6	6	9	10	13	16	13	13	11.0	9	9	10	9	7	6	5	2.5	13	9	9	7	6
3	6.5	6	2.5	3.5	3.5	5.5	4.5	7.5	7	11	10.0	9	7	8	7	7	8	8	6	3	5	5	4.5	4
Average	4.7	5.2	4.5	3.9	3.9	4.9	6.1	8.7	8.5	8.7	7.5	6.4	6.6	7.5	7.2	7.7	7.8	7.5	6.4	6.2	5.1	4.9	4.9	4.6

TABLE XX.—*Evaporation rate (in grams per hour) during rye transpiration period at Akron, Colo., in June and July, 1914*

Date.	Hour ending—																							
	A. M.											Noon.	P. M.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
June 22	20	20	20	20	20	212	368	420	460	520	600	620	700	700	680	610	530	360	120	16	26	20	40	0
24	60	60	60	40	40	30	70	360	500	540	640	720	740	760	720	620	520	420	260	20	0	0	0	0
27	0	0	0	0	46	106	240	480	540	580	790	790	760	700	600	620	360	360	320	160	0	0	0	96
29	60	0	0	0	0	60	240	360	400	560	660	780	820	840	720	680	500	420	250	170	120	46	36	50
July 2	10	10	0	0	46	94	220	440	580	720	780	820	680	800	720	600	380	230	130	60	0	0	0	0
3	0	0	0	0	10	140	220	280	600	840	820	840	900	800	760	700	480	360	140	130	90	110	20	60
Average	25	15	14	10	27	107	226	390	514	626	715	762	767	767	700	638	462	358	203	93	39	29	16	34
Percentage of maximum	3	2	2	1	4	14	29	51	67	82	93	99	100	100	91	83	60	47	26	12	5	4	2	4

A striking feature of the radiation curve is the rapid rise in radiation intensity during the early morning hours. Reference to the graphs will show that the radiation has attained approximately one-half its maximum value two hours after sunrise, and a corresponding decrease occurs in the late afternoon.

The mean air temperature during the rye transpiration period ranged from 54° F. at 4.30 a. m. to about 83° F. at 4.30 p. m. The maximum air temperature thus occurs four hours later than the solar-radiation maximum. The wet-bulb-depression graph is similar in form to the air-temperature curve, and its maximum occurs at approximately the same time. The maximum of the evaporation curve, on the other hand, corresponds with that of solar radiation, but the slope of the evaporation graph is more nearly uniform during the morning and afternoon than that of the radiation graph.

The transpiration graph of rye shows the same flattening during the middle part of the day that was observed with wheat and oats in 1912. With rye this flattening begins at 8.30 a. m., and continues until 1 p. m., the slope being nearly uniform during this period. During the late afternoon the transpiration falls rapidly and the night transpiration is seen to be very low.

The mean wind velocity in miles per hour is plotted at the bottom of figure 6. The maximum rate of about 9 miles per hour occurs from 8 to 10 o'clock in the morning. During the night the rate is less than 5 miles per hour. There is little indication from the graphs that differences in the velocity of the wind had much influence on either the transpiration or the evaporation rate.

ALFALFA

The transpiration measurements upon alfalfa (*Medicago sativa*)[1] are the most extensive of the series and include 52 day records taken during 26 days, embracing late-season as well as midsummer measurements. The transpiration data are given in detail in Table XXI and the physical measurements in Table XXII to XXVI, inclusive. The hourly means will be found plotted in figure 7. Since the period covered by the measurements is so extended, it has seemed advisable also to separate the measurements into shorter periods for comparison. Summaries covering a short transpiration period in June and another period in October are accordingly presented in Tables XXVII and XXVIII, and are plotted in figure 15, to which reference will be made later.

[1] Grimm alfalfa, A. D. I. (Alkali and Drought Resistant Plant Investigations) No. 23.

TABLE XXI.—*Transpiration rate (in grams per hour) of alfalfa at Akron, Colo., for long periods, in 1913 and 1914*

Date.	Balance No.	Hour ending— A. M. 1	2	3	4	5	6	7	8	9	10	11	Noon. 12	P. M. 1	2	3	4	5	6	7	8	9	10	11	12
1913. July 11	A	0	0	0	0	60	90	40	110	160	180	160	120	180	220	180	200	190	160	100	30	4	4	4	4
	C	30	20	0	0	20	60	70	90	150	180	200	150	160	200	200	220	160	150	90	4	4	4	4	4
12	A	0	0	0	0	0	20	160	200	220	220	220	200	220	240	260	280	240	220	140	50	10	0	0	0
	C	6	6	8	12	12	20	140	160	180	200	190	180	220	220	240	260	220	200	120	30	10	10	10	4
Aug. 10	A	4	4	4	4	40	20	20	120	200	240	320	280	360	380	400	400	340	260	100	30	4	4	4	4
	C	2	2	2	2	2	20	80	180	240	320	320	340	360	400	420	400	340	280	80	20	14	4	4	4
14	A	4	4	4	4	4	20	120	260	300	240	380	460	500	540	600	580	560	440	100	20	10	10	10	10
	C	4	4	4	4	4	20	140	320	400	440	460	520	600	600	600	600	600	440	120	20	20	10	10	10
1914. June 18	A	8	20	20	20	30	70	260	240	200	200	280	280	380	320	340	360	340	240	140	6	6	6	6	10
	C	0	20	0	20	10	70	200	200	200	260	280	280	316	324	260	290	250	240	124	36	0	6	6	10
19	A	10	10	10	10	10	20	190	220	280	320	360	380	440	460	440	440	340	220	160	160	20	20	0	0
	C	10	0	0	0	0	70	150	220	260	280	300	320	340	380	380	360	350	310	70	70	20	0	0	0
21	A	0	0	0	0	10	20	90	220	260	320	400	430	430	460	440	400	400	300	120	66	14	4	0	0
	C	0	0	0	0	40	32	152	260	300	400	460	500	520	540	520	460	500	360	160	46	10	26	0	0
Aug. 11	A	16	52	80	32	20	160	200	160	300	320	300	440	560	600	600	560	520	420	160	30	34	20	20	32
	C	20	20	66	20	34	70	160	120	300	280	360	450	510	520	550	510	480	404	152	32	20	18	18	22
Sept. 10	A	20	0	0	0	0	10	70	330	420	420	460	560	580	580	590	524	479	216	36	19	6	6	6	6
	C	20	0	0	0	0	6	54	280	360	380	440	500	530	560	540	490	450	202	38	20	0	0	0	0
18	A	20	34	16	0	0	20	220	460	620	740	780	820	840	820	800	760	500	190	30	60	0	0	0	0
	C	16	24	0	0	0	0	160	460	560	620	680	720	740	760	710	690	500	188	22	40	10	0	0	0
19	A	0	0	0	0	0	0	124	356	540	640	660	680	820	800	760	640	530	220	30	10	10	10	10	6
	C	10	20	10	0	0	0	110	340	450	550	620	660	680	700	670	620	460	200	20	20	10	10	4	6
20	A	6	6	34	6	0	0	40	320	490	660	740	740	780	750	710	600	428	54	40	20	0	0	0	0
	C	6	24	10	10	0	0	50	280	400	550	590	620	680	660	660	590	400	60	40	20	0	0	0	0
23	A	6	6	26	34	20	8	120	120	260	350	430	470	454	406	340	360	240	104	32	32	14	20	10	14
	C	0	0	0	20	10	10	88	52	180	228	282	290	320	320	300	340	180	90	24	16	10	14	6	0
24	A	12	34	0	0	0	44	116	280	360	420	480	510	480	440	380	380	310	100	34	28	26	12	32	16
	C	10	10	10	10	16	4	80	220	250	330	360	440	410	430	400	360	260	100	20	10	10	16	20	20
25	A	40	30	16	14	20	20	120	380	440	580	620	660	710	720	670	620	332	180	28	30	24	36	10	24
	C	20	14	10	16	10	34	150	290	360	440	480	520	540	560	540	500	320	84	36	16	24	10	10	20
26	A	14	46	10	16	14	8	100	342	436	514	600	700	780	760	760	610	470	136	20	34	24	46	30	20
	C	16	14	10	20	0	10	100	240	320	340	440	500	520	580	540	500	360	128	24	22	16	30	6	6
30	A	6	6	6	20	40	20	120	260	460	640	720	800	840	700	700	680	370	74	12	14	14	26	40	0
	C	10	6	20	16	10	20	80	240	400	510	550	620	640	600	600	520	340	40	20	10	10	0	0	0
Oct. 5	A	40	0	0	0	0	0	72	220	344	410	500	540	560	560	560	500	400	100	60	40	10	10	20	0
	C	10	20	6	14	6	14	60	150	230	330	370	300	340	400	360	360	240	100	20	40	6	6	6	0

6	A	0	0	0	26	14	20	100	90	230	380	400	440	400	380	360	420	220	20	20	12	8	6	6	2
	C	0	0	0	20	0	0	14	66	160	240	300	380	380	420	400	400	260	40	10	10	10	10	10	10
14	A	0	0	0	0	0	0	10	60	70	140	130	100	200	220	160	170	110	40	14	16	30	10	10	0
	C							4	16	50	80	70	120	200	180	180	180	160	20	0	0	0	0	0	0
15	A	16	4	0	20	20	20	10	10	60	240	260	380	300	300	300	380	120	24	16	16	24	0	0	0
	C	0	0	20	0	20	20	6	14	160	220	240	320	290	290	260	260	140	50	10	0	0	0	20	20
16	A	40	0	0	0	0	60	54	186	240	260	360	340	360	380	340	320	80	80	16	34	40	30	0	40
	C	0	0	0	0	0	20	20	120	200	220	280	300	320	320	310	320	150	40	14	18	18	10	16	64
17	A	40	0	0	0	20	20	40	160	320	470	470	540	560	570	490	430	230	30	10	20	74	26	16	44
	C	10	10	16	10	6	6	20	130	250	360	360	440	460	480	460	380	210	40	30	30	20	24	14	10
18	A	0	0	20	20	20	40	60	220	360	440	540	600	580	560	440	400	220	40	10	10	60	80	20	20
	C							20	160	240	340	360	460	440	420	420	370	190	48	8	22	46	20	26	14
19	A	0	0	0	0	0	0	34	186	300	430	480	490	520	500	480	400	210	50	26	14	30	30	8	8
	C	0	0	0	0	0	0	16	124	208	308	400	440	440	440	400	350	170	34	16	20	10	14	8	10
20	A	24	14	6	6	6	24	54	246	340	480	610	610	690	630	600	460	220	60	16	34	10	10	10	16
	C	14	12	12	10	16	20	20	150	230	400	460	460	510	500	490	370	174	24	8	24	8	8	14	10
Average		10	10	9	9	12	25	90	204	293	367	414	451	481	482	464	434	313	151	53	27	16	13	10	10
Percentage of maximum		2	2	2	2	2	5	19	42	61	76	86	94	100	100	96	90	65	31	11	6	3	3	2	2

TABLE XXII.—*Hourly solar radiation intensity (differential temperatures in degrees Fahrenheit) during alfalfa transpiration period at Akron, Colo., for long periods, in 1913 and 1914*

Date.	Hour ending—														
	A. M.							Noon.	P. M.						
	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
1913.															
July 11	6	19	31	37	40	43	44	45	45	45	40	37	36	31	20
12	8	15	10	36	39	41	43	44	45	44.5	43	41	38	31	29
Aug. 10	0	11	22	35	39	41	43	43	43.5	43	41.5	39	36	28	10
14	4	17	32	37	40	42	45	46	46	45.5	44	36	36	27	7
1914.															
June 18	14	32	40	45	46	47	48	48	48	46	43	41	37	26	10
19	20	34	41	45	46	46	48	48	48	47	46	42	37	24	5
21	2	21	37	42	45	46	47	48	45	47	44	37	38	36	21
Aug. 11	3	12	36	44	48	49	50	51	51	50	49	45	40	32	14
Sept. 10	2	5	28	37	42	44	45.7	46	48.8	45.5	44	41	35	22	2
18	0	6	29	38	42	44.5	45.5	45.5	45	44	42	39	33	28	0
19	0	5	28	39	42	43.5	45	45	45	44	42	38	31	14	0
20	0	4	28	39	42	43.5	44.5	45.5	45	43	42	38	28	0	0
23	0	12	34	44	47	48	48	48.5	47	46	43	39	32	12	0
24	0	10	35	42	45	46	47	47	46.5	45	42	38	31	13	0
25	0	3	26	38	42	43.5	44.5	45	44.5	43	42	38	....	....	....
26	0	6	29	39	43	45	45.5	46	45	43	41.5	37	29	10	0
30	0	4	24	37	41	42.5	44	45	44.5	43	41	38	29	7	0
Oct. 5	0	0	29	42	45	46	46.5	45	45.5	44	42	39	31	10	0
6	0	3	35	43	45	47	47	46.5	45	43.5	41.5	38	28	4	0
14	0	0	23	42	46	48	48	48.5	47	45	42.5	38	30	18	0
15	0	0	22	40	44	45	45	45	44	42.5	40	36	26	2	0
16	0	0	26	40	44	44	44	44.5	43.5	42	39	33	18	0	0
17	0	0	22	38	41	42	43	43	42	40.5	39	32	18	0	0
18	0	0	14	38	42	43	43	43.5	42.5	40	37	29	9	0	0
19	0	0	22	38	40	42	42.5	42.5	42	40.5	38	33	19	0	0
20	0	0	21	37	41.5	41.5	41.5	42	41.5	40	37	33	19	0	0
Average	2.3	8.4	28.6	39.7	43	44.4	45.3	45.6	45.2	44	41.8	37.5	29.7	15.1	4.7
Percentage of maximum	5	18	63	87	94	97	99	100	99	97	92	82	65	33	10
Calories per sq. cm. per minute	.06	.24	.80	1.11	1.20	1.24	1.27	1.28	1.27	1.23	1.17	1.05	.83	.42	.13

TABLE XXIII.—*Hourly temperatures (in degrees Fahrenheit) during alfalfa transpiration period at Akron, Colo., for long periods, in 1913 and 1914*

Date.	Hour ending—																							
	A. M.											Noon.	P. M.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
1913.																								
July 11	76	69	61.5	59.5	58	57.5	57.5	59	64	67	71	73	75.5	76	76.5	76.5	76.5	75.5	74	71.5	65	61.5	57	54
12	50	49.5	48.5	47.5	49	53	59	66	71	74	77	80	83	85	87.5	88	88.5	87.5	86	80	73	68	68	69
Aug. 10	65.5	65	64	60.5	59	59	60.5	65	70	73	76	78	80	82	83.5	84	84	83.5	71	67	73	71	68	65
14	63	62	60	59.5	58.5	58.5	63	69	73	78	83	86	89	91	91	92	91.5	91	86	80	76	74	71	69
1914.																								
June 18	59	59	58	58	59.5	60	64	68	72.5	77.5	82	84	86	88	88.5	89	89	88	84	75	68	65	64	65
19	65	62	61.5	61	59	58.5	64	73.5	79	82	85	88	89	90	90.5	90.5	89.5	88	83	77.5	75	73	68	65
21	61	59	58	56	54	57.5	62.5	67.5	72	75.5	81	83.5	85	87	88	86	86	86	82	76	76	75	67	65
Aug. 11	60	60.5	61.5	60	58	54	54	58	62	67	70	73.5	77	79	80	80.5	80	79	75	67	62	60	60	60
Sept. 10	55.5	55	52.5	52	51	52	55	60	68	71	74	77	79	80.5	81	80.5	80	78	69	63	58	55.5	53	52.5
18	61	63.5	62.5	59	58	60	71	80	84	86	87.5	88	88.5	88	87	85	82	76	71	70	68	66	64.5	63.5
19	62.5	61.5	61	60.5	59.5	60	65	72	78	80	83.5	84	85	85.5	84.5	83	80	74	68	65	63	63	61	60
20	58.5	58	57	56	54	54.5	63	69	74	79.5	82	84	86	86.5	86	84	79	73	73	71	69	68.5	67	64
23	42.5	41	41.5	41	39	38	44	52	58	62	65	67	68	69	70	70.5	68.5	63	55.5	52	46	42.5	41.5	43
24	45	44	43.5	40	39.5	43.5	50	62	67.5	70.5	73	75	76.5	77.5	78	78	77	71	61	55	52	51	48	50.5
25	54.5	54.5	54	53	52.5	51.5	56	63	71	75.5	77.5	80	81	81.5	81.5	81	79	74	67	63.5	61.5	61	49	49
26	57.5	57	55.5	63	49.5	47.5	49	57	67	71	78	81	84	85	85	85	83	77.5	68	62.5	56.5	58.5	58	55.5
30	47	46	47	48	47.5	47	51	62	72	76	78	80	80.5	80.5	80.5	80	78	72	64	60	57	55	54	52
Oct. 5	34	33	34	34	34.5	35	37	43	53	57	60	62	64.5	66	66.5	66	64	58	51	51	47	45	43.5	43
6	37	34	31	29.5	30	31	34	42	54	62.5	66	69	71	71.5	71.5	71	68	61	54	51	50	47	42	42
14	23	22.5	24	24.5	24	24	27	34	42	47	51	53	55	58	59.5	59	57	52	44	37	31	30	32	33.5
15	33	32	31	31	32.5	33	36	44	51.5	56.5	62	64	66.5	68	69	68	64	59	51	46	40.5	38.5	36	35.5
16	36	35.5	36	33.5	33.5	33.5	37	44	54	59	65	69	71	73.5	74.5	75	73	64	53	51	48.5	47	48.5	46
17	45	44.5	44.5	44.5	44	44	42.5	48	61	69	73	76	78.5	80	80.5	80	77	65	55	52.5	54.5	55	51.5	50.5
18	47	40.5	42.5	41.5	38.5	39.5	40	53	60	65.5	70.5	73	74.5	75.5	75.5	74.5	70	54	51.5	50	48	48.5	48	48.5
19	44	41	39	38.5	38	36.5	37	49	62	67	70.5	72	73.5	74.5	74	73	69	60	53	50	48.5	47	47	46
20	44.5	45.5	45	44.5	42.5	40	40	53	67	72	75.5	78	80	81	80.5	78	72	64.5	57.5	56	54.5	52.5	51.5	50.5
Average	51	49.8	49	48.3	47	47.2	50.7	58.2	65.7	69.7	73.8	76.1	77.9	79.2	79.7	79.1	77	72	65.6	61.6	58.5	56.8	54.6	53.8
Average in degrees centigrade	10.6	9.9	9.4	9.1	8.3	8.4	10.4	14.6	18.7	20.9	23.2	24.5	25.5	26.2	26.5	26.2	25	22.2	18.7	16.4	14.7	13.8	12.6	12.1
Percentage of maximum range	12	9	6	4	0	1	11	34	57	69	82	89	95	98	100	98	92	76	57	45	35	30	23	21

TABLE XXIV.—*Hourly wet-bulb depression (in degrees Fahrenheit) during alfalfa transpiration period at Akron, Colo., for long periods, in 1913 and 1914*

Date.	Hour ending—																							
	A. M.											Noon.	P. M.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
1913.																								
July 11	10	4.5	3.5	4	4.5	5.2	8	12	14	16	19	20	21	21	21	20.5	20	19.5	17	14.5	12	10	9	7.5
12	7	6	5.5	6	7	13	18	20	21.5	23	24.5	26	28	29	29.5	28	28	27	24	18	15	14	13	11
Aug. 10	6.5	5.5	4	3	2.5	4	6	8.5	10.5	13	14.5	16.5	19	20	22	22	22.5	21	18	14	11	8	6	5
14	5	4	3	2.5	2	2	5	9	12	16	17	20	22	24.5	25	26	25	24	18	15	13	11.5	10	9
1914.																								
June 18	.....	.....	.....	.....	4.5	5	8	10	14	16	20	21.5	24	26	27	25.5	24	20	15	7	5.5	6	8	9
19	6	4.5	4.5	4	3	6	10	12.5	13	19	24	25	25	25	24	23	22	18	13	12	14	9	7	6
21	4	4	4.5	4.5	2.5	4	8	9	10	13	19	21	22	25	26	25	25.5	24	17	16	17	15	9	2
Aug. 11	8.5	7.5	6	4.5	4	1.5	3	5.5	8	10.5	13.5	18.5	21	23	24	24.5	25	24.5	19	14	13	10.5	8.5	7
Sept. 10	2.5	1	.5	0	0	0	.5	5	13.5	17.5	23.5	26	26.5	27.5	27	26.5	25.5	22.5	16	13	10.5	8.5	7.5	6.5
18	6	6	6	5	4	4	8	16	22	27	29.5	30	29	29	28.5	27	26	22	17	14	10	8	6	5.5
19	4.5	3.5	2	2	2	1	2	8	13	17	21	23	23	24	24	23	21	19	17	15	12.5	10	8	6
20	5	4	3	3	1.5	5	2	7.5	12.5	17.5	21	21.5	24	25	25	24.5	23	18	15	15	13.5	12	12	11
23	4.5	3	4	2.5	2	1	3	7	10	13	15	16	17	17	18	18	19	14	10.5	8	7	4	4	3.5
24	4.5	4.5	4	2.5	1	2	5	11	15	18	20	22	23	24	25	25	24	20	15	11	9.5	8.5	7.5	8.5
25	9	10	10	9.5	8.5	8.5	10	15	20	23	26	27	28	28	28	27	25	22	17	14	12	12	11	11
26	10.5	10	9	7	5	4	5	10	16	18	22	24.5	27	28	28.5	27	26	23	16	14	11	11	13	12
30	7	6	6	7	8	7	5	11	16	23	23.5	26	28	28	28	24	19.5	19	17	14	12	10	9	7
Oct. 5	1	1	1	1	1	1	3	7	13	18	19.5	20	22.5	23.5	25	24	22	17	13	12	9	7.5	6.5	5.5
6	3.5	2.5	2	1	5	1	1	6	11	15	19	21	24	24.5	25	24.5	22	16	12	10	8	7	4.5	4
14	3	1.5	3	3.5	.....	.....	11	8	6	7	9	11	12.5	14.5	16.5	17	15	12	9	5	2.5	1	1	2
15	2.5	1.5	.5	0	.5	1	3	8	11	15	18	19	21	22	22.5	22	18	14	12	10	6	4	2.5	2
16	2	2	2	1	1	1	1	6	11	15	19	21	23	23	24	25	23	19	13	12	10.5	10	10	8.5
17	7.5	7	7	7.5	7.5	7	3	7	13	21	23	25	27	28	28.5	28.5	26	19	14	12	12	13	11	10
18	10	5	5	6	3	3	5	13	16	20	22	23.5	23.5	25	24.5	25	22	16	13	12	11	10.5	10.5	10.5
19	9	5	3	1.5	1	.5	1	7	14	17	20	21.5	22	22	22	21	17	13	9	7.5	7.5	6	6.5	6
20	6	5	6	5.5	3.5	2.5	3	10	15	21	25	27	29	30	30	28	24	18	13	10	8	6	5	4
Average	5.8	4.6	4.2	3.8	3.2	3.6	5.3	9.6	13.5	17.3	20.3	22.1	23.6	24.5	25.0	24.3	22.7	19.3	15.0	12.3	10.5	9.0	7.9	6.9
Percentage of maximum range	12	6	5	3	0	2	10	29	47	65	78	87	94	98	100	97	89	74	54	42	33	27	22	17
Saturation deficit in inches	0.126	0.092	0.091	0.087	0.066	0.075	0.107	0.226	0.372	0.495	0.605	0.685	0.754	0.794	0.827	0.794	0.715	0.572	0.389	0.308	0.246	0.218	0.193	0.161
Percentage of maximum	15	11	11	11	8	9	13	27	45	60	73	83	91	96	100	96	86	69	47	37	30	26	23	19

TABLE XXV.—*Wind velocity (in miles per hour) during alfalfa transpiration period at Akron, Colo., for long periods, in 1913 and 1914*

Date.	Hour ending—																							
	A. M.											Noon.	P. M.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
1913.																								
July 11	10	10	7	7	9	13	12	11	9	9	11	11	10	8	7	11	7	7	8	6	4	2	0	0
22	.5	.5	1	1	3	4	11	12	15	16	15	14	12	8	9	8	9	7	7	3	3	5	8	8
Aug. 10	......	......	......	......	......	......	......	......	12	11	10	10	8	8	7	7	6	7	5	3	4	4	.5	.5
14	1	1	2	1	2	1	1	7	5	5	3	2	3	3	3	5	8	7	3	1	.3	.3	.3	2
1914.																								
June 18	2	2	3	5	4	5	8	10	10	8	7	7	6	7	5	2	3	2	2	1	.5	.5	.5	.5
19	1	2	2	3	2	3	4	4	3	4	8	8	8	7	6	8	10	7	7	3	8	4	2	2
21	......	......	......	......	......	......	......	7	7	8	6	6	7	5	5	8	9	.3	2	3	4	5	5	8
Aug. 11	9.5	10	8.8	7.3	6.0	6.7	8.5	10.3	11	9.6	8.2	8.1	8.2	6.5	5.9	4.4	5.3	5.2	2.8	1.5	1.9	2.5	3.9	4.1
Sept. 10	4	1.7	1.6	1.1	1.9	4.1	4.4	7.2	6.5	10.2	10.8	9.5	8	7.5	6.2	7.1	6	3.7	3.4	3.2	1.1	1.4	1.7	1.8
18	4	5.4	6	6.3	5	4.8	5.1	5.8	7.4	7.9	7.5	7.2	8.6	9.1	8.5	8.6	7.7	8.5	5.5	8.2	9.7	7.4	8	9.5
19	9.2	8.3	6.5	4.5	3.2	3.5	4.8	6.7	8.7	10	10	7.8	8.8	7.2	7.8	8.0	7.8	6.2	5.3	5.3	6.6	1.0	9.2	8.8
20	8	8.6	9	8.5	5.5	5.5	7.2	10.9	9.5	11	12	12.8	11.1	11	10.5	10	8.5	3.8	7.3	10	7	9.6	6	......
23	3.9	3.4	5.2	5	6.3	7.2	9.8	4.6	3.8	4.8	5.5	6.1	7.6	7.1	4.9	6.5	7.5	3.1	3.3	1.8	1.2	2.3	2.7	3.0
24	2.9	4.0	3.7	2.1	2.5	4.3	4.1	5.2	2.6	3.1	4.0	5.7	4.2	3.6	3.4	3.2	1.5	1.6	1	1	2.2	3.1	3.7	4.7
25	5.2	6.1	7.3	5.9	5	5.1	5.2	7.5	8.1	9.7	10.6	10.4	8.8	8.5	7.8	8.3	8.3	5.2	4.0	4.3	6.1	7.5	8.2	9.4
26	8.8	9.6	8.8	5.9	3.3	3.0	3.8	5.2	7.1	5.2	3.1	3.4	5.4	5.1	5.9	5.0	4.4	2.6	2.1	2.4	2.8	3.9	5.0	5.3
30	2.2	2.3	2.5	4.3	6.5	5.5	4.6	4.4	4.7	10.6	11	10.3	9	8.9	8.2	......	......	......	......	......	......	......	......	......
Oct. 5	4.1	4.5	6.8	5.0	5.0	4.8	4.9	6.8	11	14.5	13.5	14.5	13.6	14.0	12.3	11.5	9.3	5.0	4.6	5.2	4	2.1	2.2	1.9
6	1.2	1.5	1.5	2.4	3.3	5.5	9	9.2	4.6	2.0	2.4	3.1	3.8	4.8	6.4	8.4	8.2	5.4	4.1	2.3	1.8	1.4	1.1	1.1
14	2.6	1	1	.9	.8	.3	.2	1.2	10.9	11.9	9.8	6.2	5.9	4.9	6	3.9	4.1	1.5	1.6	1.2	2.1	2.6	3.5	4.0
15	4.6	5.4	6.9	6.8	8	7	7.5	6.2	7.3	9.1	10	10.4	11.4	11.6	10.5	10.8	7.9	1.4	2.6	1.5	1.5	2.2	2.2	2.8
16	4.7	5	4.7	2.7	2.6	4.7	8.9	12.0	12.0	14	10	7.8	4.3	4.3	2.5	2.9	7.4	2.5	2.6	3.2	4.6	5.7	5.1	5.9
17	8	7.8	7	7.8	6.5	5.2	6.6	5.4	3.9	6.2	4.7	.4	6	5.3	5.5	6.3	4.8	2.3	3.6	4.6	4.5	5.4	4.1	5.1
18	5.4	4	6.1	6.5	5.3	10	2.6	6.2	7.3	5.3	10.7	11.8	7.1	5.3	4.8	3.9	3.2	3.4	2.9	1.8	3	4.6	4.7	4.7
19	3.2	2.5	2.8	3.3	3	2.4	1.9	1.7	3.4	4.1	5.5	5.8	7.0	7.0	6.8	6.5	3.8	1.9	1.2	2.3	3.2	3.9	4.5	3.8
20	4.9	4.4	3.9	3.4	2.6	2.1	2.9	3.5	2	4.3	3.4	8.6	8.6	8.3	9.7	10.8	8.6	6.4	4.6	6.7	8.5	7.5	9.5	9.9
Average	4.6	4.6	4.8	4.4	4.3	4.9	5.8	6.8	7.4	8.3	8.2	8.1	7.8	7.2	6.8	7.1	6.7	4.4	3.9	3.5	3.6	3.8	4.1	4.5

TABLE XXVI.—*Evaporation rate (in grams per hour) during alfalfa transpiration period at Akron, Colo., for long periods, in 1913 and 1914*

Date.	Hour ending— A. M. 1	2	3	4	5	6	7	8	9	10	11	Noon. 12	P. M. 1	2	3	4	5	6	7	8	9	10	11	12
1913.																								
July 11	0	0	0	0	...	...	...	...	380	600	...	560	640	700	840	660	400	300	300	120	80	20	12	10
12	20	20	20	40	20	60	360	400	580	1,040	740	760	860	780	740	640	520	440	280	180	80	120	160	100
Aug. 10	10	10	6	6	6	80	140	340	480	580	780	760	700	800	780	600	520	360	120	80	40	22	2	2
14	2	2	2	2	2	20	160	400	540	440	620	680	680	740	580	520	520	380	120	60	20	30	40	50
1914.																								
June 18	0	0	0	0	40	180	360	440	600	560	920	860	900	900	520	530	440	220	160	20	0	10	10	40
19	20	10	10	0	20	100	200	340	520	700	820	940	920	880	720	700	640	400	200	140	60	0	0	0
21	0	0	0	0	20	20	140	340	500	640	800	800	780	780	760	660	560	280	80	142	180	200	20	140
Aug. 11	94	88	112	20	72	210	384	340	360	300	432	760	780	660	660	480	400	280	90	60	50	30	46	32
Sept. 10	0	0	0	0	0	8	62	480	510	680	680	720	720	680	590	536	334	150	150	70	30	40	12	38
18	34	36	0	0	0	4	108	248	460	620	700	840	880	780	720	640	460	266	160	120	70	40	50	40
19	40	20	0	0	0	0	68	212	400	620	780	780	760	700	680	500	400	260	180	140	120	120	94	60
20	50	30	36	16	34	0	70	250	420	650	760	850	940	760	700	590	450	200	140	40	10	10	30	0
23	10	16	34	50	0	0	100	120	260	460	640	680	680	540	480	500	200	60	80	20	40	40	40	20
24	0	0	0	0	0	60	80	240	290	480	630	680	600	560	480	388	232	110	60	40	30	66	80	54
25	80	60	90	38	52	0	132	288	420	660	850	890	860	740	688	592	400	220	160	110	110	148	140	166
26	146	140	154	106	40	0	100	140	420	440	590	640	720	680	600	480	300	160	100	100	70	60	52	76
30	32	28	32	20	20	0	20	140	340	800	840	860	840	720	660	540	340	200	120	110	90	100	60	30
Oct. 5	0	0	0	0	0	0	14	92	194	550	670	700	660	640	600	430	324	126	80	80	40	80	0	0
6	0	0	0	0	0	0	48	44	168	340	440	560	540	480	480	420	280	120	30	40	24	12	6	36
14	0	0	0	0	0	0	8	112	234	280	320	340	400	380	400	260	80	0	0	0	0	0	0	0
15	20	50	50	30	150	40	40	100	60	180	580	620	660	540	500	400	...	...	...	...	...	...	...	...
16	...	...	...	...	...	...	80	140	260	520	620	330	470	360	240	200	160	100	40	40	40	40	40	40
17	...	...	...	...	...	...	140	180	200	240	400	600	700	600	540	460	280	120	180	110	24	148	86	130
18	30	34	56	90	56	44	100	214	406	480	700	700	460	540	400	320	160	116	44	60	116	140	100	80
19	0	0	0	0	0	0	0	68	232	370	520	550	600	520	440	352	208	70	30	40	60	52	28	12
20	28	20	60	20	20	20	50	150	180	360	620	700	700	700	620	480	320	180	90	70	50	70	14	20
Average	26	24	28	19	24	37	118	232	362	524	659	706	710	660	594	496	357	204	120	80	57	62	45	47
Percentage of maximum	4	3	4	3	3	5	17	33	51	74	93	99	100	93	84	70	50	29	17	11	8	9	6	7

TABLE XXVII.—*Summary of transpiration and environmental conditions during alfalfa transpiration period at Akron, Colo., from June 18 to 21, 1914*

Physical condition.	Hour ending—																							
	A. M.											Noon.	P. M.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Transpiration:																								
Average	5	8	5	8	17	47	174	227	250	297	347	365	404	414	397	385	363	278	129	64	12	10	2	3
Percentage of maximum	1	2	1	2	4	11	42	55	60	72	84	88	98	100	96	93	88	67	31	15	3	2	0	1
Evaporation:																								
Average	6	3	3	0	26	100	233	373	540	633	847	867	867	853	667	630	547	300	147	100	80	70	10	60
Percentage of maximum	0	0	0	0	3	12	27	43	62	73	98	100	100	98	77	73	63	35	17	12	9	8	1	7
Radiation:																								
Average	......	......	......	......	12	29	39.3	44	45.7	46.3	47.7	48.0	47.0	46.7	44.3	40.0	37.3	28.7	12.0	......	......	......	......	......
Percentage of maximum	......	......	......	......	25	60	82	92	95	96	100	100	98	97	92	83	78	60	25	......	......	......	......	......
Calories per sq. cm. per minute	......	......	......	......	0.34	0.81	1.10	1.23	1.28	1.30	1.34	1.35	1.32	1.31	1.24	1.12	1.05	0.80	0.34	......	......	......	......	......
Air temperature:																								
Average	61.6	60.0	59.1	58.3	57.5	58.6	63.5	69.6	74.5	78.3	82.6	85.1	86.7	88.3	89.0	88.5	88.2	87.3	83.0	76.2	73.0	71.0	66.3	65.0
Average in degrees centigrade	16.4	15.6	15.1	14.6	14.2	14.8	17.5	20.9	23.6	25.7	28.1	29.5	30.4	31.3	31.7	31.4	31.2	30.7	28.3	24.6	22.8	21.7	19.1	18.3
Percentage of maximum range	13	8	5	3	0	3	19	38	54	66	80	88	93	98	100	98	97	95	81	59	49	43	28	24
Wet-bulb depression:																								
Average	5.0	4.3	4.3	4.3	3.3	5.0	8.7	10.5	12.3	16.0	21.0	22.5	23.7	25.3	25.7	24.5	23.8	20.7	15.0	11.7	12.2	10.0	8.0	5.7
Percentage of maximum range	8	4	5	4	0	8	24	32	40	57	79	86	91	98	100	95	92	78	52	38	40	30	21	11
Saturation deficit:																								
Average	.136	.115	.125	.131	.087	.137	.143	.326	.420	.571	.776	.863	.935	1.018	1.043	.996	.970	.847	.591	.430	.399	.325	.239	.174
Percentage of maximum	13	11	12	13	8	13	14	37	40	55	74	83	90	98	100	96	93	81	57	41	38	31	23	17
Wind velocity	1.5	2.0	2.5	4.0	3.0	4.0	6.0	7.0	6.7	6.7	7.0	7.0	7.0	6.3	5.3	6.0	7.3	4.0	3.7	2.3	4.2	3.2	2.5	3.5

TABLE XXVIII.—*Summary of transpiration and environmental conditions during alfalfa transpiration period, at Akron, Colo., from October 16 to 20, 1914*

Physical condition.	Hour ending—																							
	A. M.											Noon.	P. M.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Transpiration:																								
Average	14	4	6	5	8	21	34	168	269	371	432	468	488	480	443	380	185	45	15	23	32	25	13	24
Percentage of maximum	3	1	1	1	2	4	7	34	55	76	89	96	100	98	91	78	38	9	3	5	7	5	3	5
Evaporation:																								
Average	19	18	39	37	25	21	74	150	256	394	572	616	586	544	448	362	226	117	77	64	58	90	54	56
Percentage of maximum	3	3	6	6	4	3	12	24	42	64	93	100	95	88	73	59	37	19	13	10	9	15	9	9
Radiation:																								
Average	.....	.....	.....	.....	.....	0	21.0	38.2	41.7	42.5	42.8	43.1	42.3	40.6	38.0	32.0	16.6	0	.....	.....	.....	.....	.....	.....
Percentage of maximum	.....	.....	.....	.....	.....	0	49	89	97	99	99	100	98	94	88	74	39	0	.....	.....	.....	.....	.....	.....
Calories per sq. cm. per minute	.....	.....	.....	.....	.....	0	0.59	1.07	1.17	1.19	1.20	1.21	1.18	1.14	1.06	0.90	0.46	0	.....	.....	.....	.....	.....	.....
Air temperature:																								
Average	40.3	41.4	41.4	40.5	39.3	38.7	39.3	49.4	60.8	66.5	70.9	73.6	75.5	76.9	77.0	76.1	72.2	61.5	54.0	51.8	50.8	50.0	49.3	48.3
Average in degrees centigrade	4.6	5.2	5.2	4.7	4.1	3.7	4.1	9.7	16.0	19.2	21.6	23.1	24.2	24.9	25.0	24.5	22.3	16.4	12.2	11.0	10.4	10.0	9.6	9.1
Percentage of maximum range	4	7	7	5	2	0	2	28	58	73	84	91	96	100	100	98	88	60	40	34	32	30	28	25
Wet-bulb depression:																								
Average	6.9	4.8	4.6	4.3	3.2	2.8	2.6	8.6	13.8	18.8	21.8	23.6	24.9	25.6	25.8	25.5	22.4	17	12.4	10.7	10.0	9.1	8.6	7.8
Percentage of maximum range	17	9	9	7	3	1	0	26	48	70	83	91	96	99	100	99	85	62	42	35	32	28	26	22
Saturation deficit:																								
Average	.129	.090	.086	.081	.061	.054	.053	.184	.348	.508	.627	.704	.745	.783	.809	.785	.662	415	.278	.235	.214	.197	.185	.164
Percentage of maximum	16	11	11	10	8	7	7	23	43	63	77	87	92	96	100	97	82	51	34	29	26	24	23	20
Wind velocity	5.2	4.7	4.9	4.7	4.0	4.9	4.6	5.8	5.7	6.8	6.9	7.6	6.6	6.4	5.9	6.8	5.6	3.3	3.0	3.7	4.8	5.4	5.6	5.9

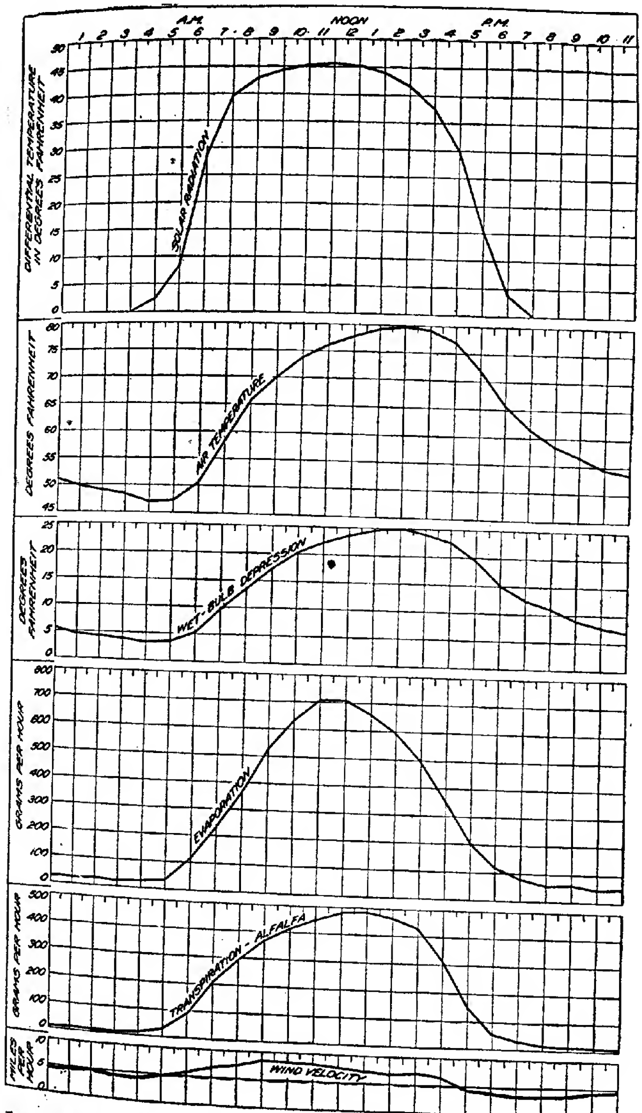

FIG. 7.—Composite transpiration graph of alfalfa, with environmental graphs and evaporation graph for corresponding period.

Considering now the composite graphs based upon the records obtained during 26 clear days, it will be seen that the radiation graph is similar in form to those already discussed, save that the radiation tends to change less rapidly during the early-morning and late-afternoon hours, owing to the fact that the length of the day was not uniform throughout this long period. The slight variation in radiation intensity during the midday hours and the marked changes between 5 and 7 a. m. and 4 and 6 p. m. are in conformity with what has already been noted of the other radiation curves.

The composite temperature graph shows a daily range of 33 degrees, the minimum (47° F.) occurring between 4 and 5 a. m., and the maximum (80° F.) between 2 and 3 p. m. The graph showing the wet-bulb depression is very similar in form to the air-temperature graph, and the maxima and minima correspond. This is to be expected, since with an unvarying amount of water vapor in the air, the wet-bulb depression would be determined by temperature fluctuations. Furthermore, since the observations are confined to clear days, sudden changes in absolute humidity are not encountered.

The evaporation graph representing the alfalfa period is nearly symmetrical with respect to noon, and the slope of the graph changes but slightly during either the morning or afternoon hours. The greater portion of the daily evaporation, however, takes place during the afternoon, owing probably to the higher temperature prevailing during this part of the day.

The transpiration graph shows a very low rate of transpiration during the night. The rate gradually increases from about one hour after sunrise to the maximum at 1.30 p. m. After 2.30 p. m. the curve falls rapidly until sundown and remains practically constant throughout the night. By far the greater part of the daily transpiration occurs during the afternoon. This asymmetry with respect to midday is much more apparent in the transpiration graph than in the evaporation graph.

At the bottom of figure 7 the mean velocity of the wind is shown for each hour in the day. During daylight hours the rate is approximately 7 miles per hour and during the night about 4 miles per hour. It is apparent from Table XXIV that the air is never still for an hour at a time.

AMARANTHUS

The transpiration data so far presented have been confined to crop plants. It is also desirable in this connection to study the transpiration of weeds or native plants which have shown themselves adapted to regions of limited rainfall. To this end, *Amaranthus retroflexus* was selected as a plant widely distributed throughout the cultivated areas of the United States. Amaranthus is also one of the most efficient plants known as regards the use of water, its water requirement at Akron being below 300, thus comparing favorably with the best of the prosos, millets, and sorghums, the most efficient crop plants known.

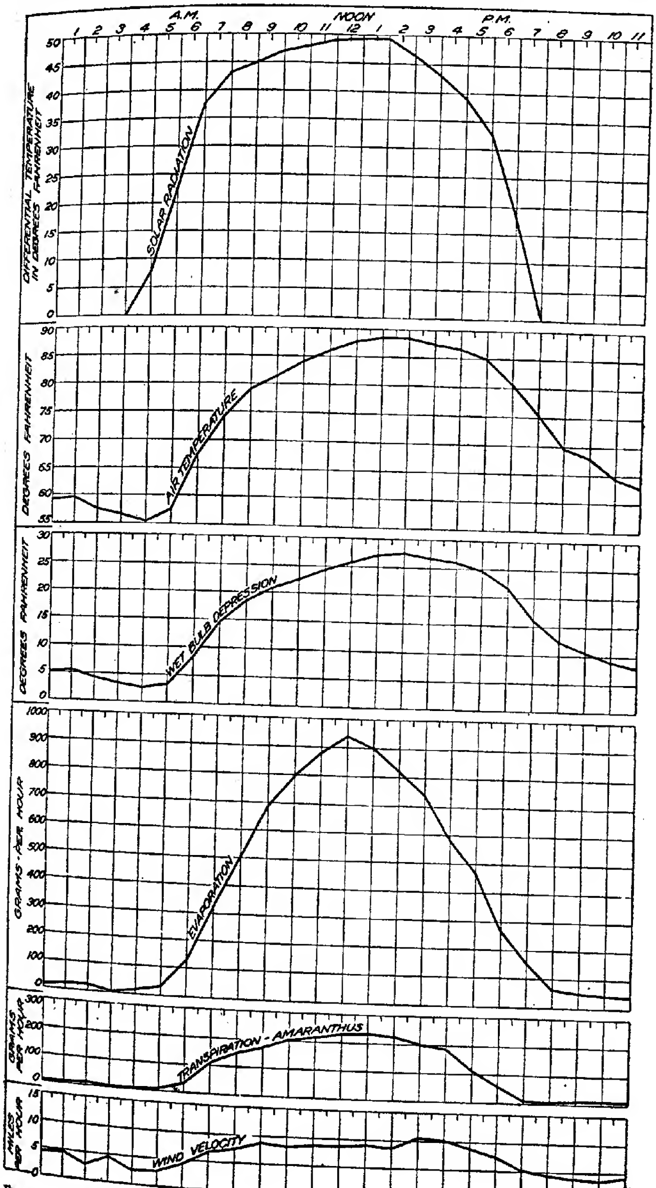

FIG. 8.—Composite transpirat...

TABLE XXIX.—*Transpiration rate (in grams per hour) of Amaranthus retroflexus at Akron, Colo., from July 7 to 9, 1914*

Date.	Balance No.	Hour ending— A. M. 1	2	3	4	5	6	7	8	9	10	11	Noon. 12	P. M. 1	2	3	4	5	6	7	8	9	10	11	12
July 7	A	0	0	0	20	0	0	15	65	80	90	150	140	168	192	180	140	120	104	96	0	0	0	0	0
	C	0	0	0	0	0	0	16	74	90	100	180	180	210	220	200	180	140	110	92	16	12	0	0	0
8	A	0	0	0	0	6	8	40	140	140	180	210	230	220	220	220	240	220	100	26	6	6	20	10	10
	C	0	20	20	0	6	10	46	140	200	240	220	280	260	260	270	250	240	140	62	8	8	4	4	4
9	A	10	10	20	0	0	10	26	94	200	200	200	200	220	280	250	170	180	100	40	5	5	5	5	20
	C	4	4	20	0	0	10	50	160	200	230	250	260	280	230	220	220	230	120	44	6	6	24	50	24
Average		2	6	10	3	2	6	32	112	152	173	202	215	226	234	223	200	188	112	60	7	6	9	12	10
Percentage of maximum		1	3	4	1	1	1	14	48	65	74	86	92	97	100	95	86	80	48	26	3	3	4	5	4

TABLE XXX.—*Hourly solar radiation intensity (differential temperatures in degrees Fahrenheit) during Amaranthus retroflexus transpiration period at Akron, Colo., from July 7 to 9, 1914*

Date.	Hour ending— A. M. 5	6	7	8	9	10	11	Noon. 12	P. M. 1	2	3	4	5	6	7
July 7	4.0	16	35	42	45	46	47	47	48	50	49	41	34	29	21
8	9.0	23	36	44	44	47	49.0	51	51	49	43	43	42	35	14
9	10.0	29	40	44	45	47	49.0	49	49	49	47	45	41	34	20
Average	7.7	22.7	37	43.3	44.7	46.7	48.3	49.0	49.3	49.3	46.3	43.0	39.0	32.7	18.3
Calories per sq. cm. per minute	0.21	0.64	1.04	1.21	1.26	1.32	1.34	1.37	1.38	1.38	1.30	1.20	1.09	0.92	0.51
Percentage of maximum	16	46	75	88	91	95	98	99	100	100	94	87	79	66	37

TABLE XXXI.—*Hourly temperatures (in degrees Fahrenheit) during Amaranthus transpiration period at Akron, Colo., from July 7 to 9, 1914*

Date.	Hour ending—																							
	A. M.											Noon.	P. M.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
July 7	60	59	57.5	57.5	56	57	63	68	72	74	78	81	83	84	84.5	84	83	81.5	78	73	69	67	63	60
8	58	60	56	54	53	58	70	77	82	8[illegible]	87	89	91	92	91.5	90.5	89	88	83	77	71	70	65	62
9	60	60	59	58	57	58	70	78	83	85	87	88	89	89.5	89.5	89	88	86	81	76	68	64	65	66
Average	59.2	59.6	57.4	56.5	55.3	57.6	67.7	74.3	79.0	81.3	84.0	86.0	87.7	88.5	88.5	87.8	86.6	85.2	80.6	75.3	69.3	67.0	64.3	62.7
Average in degrees centigrade	15.1	15.3	14.1	13.6	12.9	14.2	19.8	23.5	26.1	27.4	28.9	30.0	30.9	31.4	31.4	31.0	30.3	29.4	27.0	24.1	20.7	19.4	17.9	17.1
Percentage of maximum range	12	13	6	4	0	7	37	57	71	78	87	93	98	100	100	97	94	90	76	60	42	35	27	22

TABLE XXXII.—*Hourly wet-bulb depression (in degrees Fahrenheit) during Amaranthus retroflexus transpiration period at Akron, Colo., from July 7 to 9, 1914*

Date.	Hour ending—																							
	A. M.											Noon.	P. M.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
July 7	4	4	2.5	3.0	1.0	0.5	4	8	10	11	14	17	19	21	22	22	20	20	18	13	10	8	6	4
8	3	4	4.0	2.0	2.0	3.0	8	17	21	25	26	27	28	29	20	27	28	26	23	17	14	13	11	10
9	8	8	6.0	5.0	5.0	6.0	13	19	24	26	27	29	30	31	31	31	30	28	24	18	13	11	10	10
Average	5.0	5.3	4.2	3.3	2.7	3.2	8.3	14.7	18.3	20.7	22.3	24.3	25.7	27.0	27.3	26.7	26	24.7	21.7	16.0	12.3	10.7	9.0	8.0
Percentage of maximum range	9	11	6	2	0	2	23	49	63	73	80	88	94	99	100	98	95	89	77	54	39	33	26	22
Saturation deficit, inches	0.126	0.137	0.097	0.076	0.067	0.078	0.238	0.498	0.621	0.723	0.823	0.919	0.988	1.051	1.056	1.013	0.973	0.909	0.746	0.516	0.375	0.306	0.245	0.215
Percentage of maximum	12	13	9	7	6	7	23	47	59	68	78	78	94	100	100	96	92	86	71	49	35	29	23	20

TABLE XXXIII.—*Wind velocity (in miles per hour) during Amaranthus retroflexus transpiration period at Akron, Colo., from July 7 to 9, 1914*

Date.	Hour ending—																							
	A. M.											Noon.	P. M.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
July 7	9	3.8	3	6	3	3	4.7	6.5	8	8	7.5	9	8.5	9	8	9	8	8	8	7	4	5.5	3	2.5
8	2.5	7.5	2.5	2.8	.6	2.2	5	10	8	10	9	9	8	8	8	12	12	10	7	4	6	3	1.5	2.5
9	2	3	3	5	4	3	3	3.5	6	8	8	8	9.5	10	10	11	11	9	8	4.5	2.5	3.5	6.5	8.0
Average	4.5	4.8	2.8	4.6	2.5	2.7	4.2	6.7	7.3	8.7	8.2	8.7	8.7	9.0	8.7	10.7	10.3	9.0	7.7	5.2	4.2	4.0	3.7	4.3

TABLE XXXIV.—*Evaporation rate (in grams per hour) during Amaranthus retroflexus transpiration period at Akron, Colo., from July 7 to 9, 1914*

Date.	Hour ending—																							
	A. M.											Noon.	P. M.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
July 7	0	0	0	0	20	40	60	260	460	580	680	800	840	840	760	640	440	368	220	130	60	60	20	0
8	0	20	20	0	0	0	220	440	460	760	840	920	1,000	880	840	760	640	540	300	180	50	40	40	40
9	40	40	40	20	20	50	110	280	600	740	860	940	980	980	860	800	650	500	270	150	80	60	80	90
Average	13	20	20	7	13	30	130	326	506	694	793	887	940	900	820	733	577	470	264	154	64	54	46	44
Percentage of maximum	1	2	2	1	1	3	14	35	54	74	85	94	100	96	87	78	62	50	28	15	7	6	5	5

The transpiration measurements (see Table XXIX) include six day records on three successive days in July. The corresponding physical measurements are given in Tables XXX to XXXIV, inclusive, and the hourly means are plotted in figure 8.

While these measurements were made during what we have termed "clear days," the sky was not wholly free from cumulus cloud during the period, and this is reflected in the radiation curve, which does not quite reach its normal value during the late morning hours.

Comparison with the conditions prevailing during the rye transpiration period, which extended over the two preceding weeks, will show that the evaporation was distinctly higher during the amaranthus period. The temperature during the latter period was slightly lower, but the saturation deficit was greater. Yet the transpiration graph of *Amaranthus retroflexus* gives no indication of the flattening which is so marked in the transpiration graph of rye. There appears then to be a marked difference in this respect in the response of the two plants to the march of radiation and other cyclic factors.

GENERAL DISCUSSION

It seems desirable at this point to summarize briefly the prevailing climatic conditions at Akron during the growth period of plants and more particularly during the transpiration periods included in the above determinations (Table XXXV). Akron is located in the rolling short-grass plains of northeastern Colorado. Absolutely clear days seldom occur, but often there are days with only a few light cumulus clouds in the sky, and during such days the plants are rarely shaded from the direct rays of the sun. Such brief interruptions in the direct radiation appear to have little influence on the hourly transpiration rate. On the other hand, there are many days during which cloudiness develops, especially in the afternoon, not infrequently accompanied by light rain and high wind. The number of days which may be classified as clear in the above-defined sense forms consequently a relatively small part of the growth period of the plants. The measurements presented in this paper have been made on practically cloudless days. The radiation intensity at midday on clear days in midsummer is normally about 1.4 calories per square centimeter per minute on a surface normal to the sun's rays. In the 1912 experiments the hazy condition of the atmosphere, together with the shading effect of the hail screen, combined to reduce the maximum radiation to 0.8 calorie during the wheat transpiration period, 1.02 calories during the oat transpiration period, and 1.05 calories during the sorghum measurements. The plants during the 1912 measurements were consequently obliged to dissipate only from 60 to 75 per cent as much solar energy as in the 1914 experiments.

TABLE XXXV.—*Summary of plant and environmental data*

CROP OF 1912

	Wheat.			
	Turkey.	Kharkov.	Kubanka.	Mean for all varieties.
Transpiration period	June 25 to July 11	June 20 to July 5	June 25 to July 8	June 20 to July 11
Date of cropping	Aug. 1	Aug. 1	Sept. 3	....
Yield of dry matter ... gm.	344	366	270	
Mean maximum transpiration ... gm. per hour	258	302	174	327
Maximum transpiration ... gm. per hour	320	450	260	338
Mean maximum radiation, calories per sq. cm. per minute	....	....	....	0.8
Mean maximum air temperature ... °F.	....	....	....	86.1
Range in mean wind velocity	....	....	....	1.6 to 7.5
Mean maximum transpiration per gram of dry matter harvested	0.75	0.83	0.65	0.73

CROP OF 1912

	Oats.	Sorghum.			
	Swedish select.	Minnesota Amber.	Milo.	Dwarf Milo.	Mean for all varieties.
Transpiration period	Aug. 4 to 18	Aug. 23 to 29	Aug. 25 to 29	Aug. 24 to 29	Aug. 23 to 29
Date of cropping	Aug. 23	Sept. 26	Sept. 27	Sept. 27	....
Yield of dry matter ... gm.	411	667	509	434	537
Mean maximum transpiration, gm. per hour	271	412	430	354	406
Maximum transpiration ... gm. per hour	464	....	....	....	....
Mean maximum radiation, calories per sq. cm. per minute	1.02	....	....	....	1.05
Mean maximum wet-bulb depression	17.1	....	....	....	26.7
Mean maximum saturation deficit, inches	0.602	....	....	....	1.138
Mean maximum air temperature ... °F.	79.0	....	....	....	91.7
Range in mean wind velocity	2.5 to 6.7	....	....	....	2.4 to 8.7
Mean maximum transpiration per gram of dry matter harvested	0.66	0.62	0.84	0.81	0.76

CROP OF 1914

	Rye.	Alfalfa.			Amaranthus.
		Early period.	Whole period.	Late period.	
Transpiration period	June 22 to July 3	June 18 to 21	....	Oct. 16 to 20	July 7 to 9
Date of cropping	July 25	July 11	....	Oct. 26	July 14
Yield of dry matter ... gm.	186	157	....	176	172
Mean maximum transpiration, gm. per hour	294	414	482	488	234
Mean maximum evaporation, gm. per hour	774	867	710	616	940
Mean maximum radiation, calories per sq. cm. per minute	1.38	1.34	1.28	1.21	1.38
Mean maximum wet-bulb depression	22.8	25.7	25.0	26	27.3
Mean maximum saturation deficit, inches	0.820	1.043	0.827	0.811	1.096
Mean maximum air temperature ... °F.	82.6	89	79.7	77	88.5
Range in mean wind velocity	3.9 to 8.7	1.5 to 7	3.5 to 8.3	3.8 to 14.4	2.5 to 10.7
Mean maximum transpiration per gram of dry matter harvested	1.58	2.64	....	2.77	5.92

Since transpiration and evaporation are similarly affected by environmental factors, the loss of water from a free-water surface affords a good summation of the intensity of such factors. The total evaporation from a tank 8 feet in diameter with the water surface at ground level at Akron during the months from April to September, inclusive, is 44 inches, based on the records for seven seasons, compared with 33 inches at Dickinson in western North Dakota, 53 inches at Amarillo in the Panhandle of Texas, and 57 inches at Yuma, Ariz. In general, the evaporation increases as one proceeds from north to south through the Great Plains, and the same condition, though less marked, prevails from east to west. The transpiration conditions at Akron are probably as severe as may be found in cultivated areas east of the Rockies in this latitude (40° N.) or to the north of this parallel.

Hourly evaporation measurements with the shallow, blackened tank were not made in 1912. The evaporation rate in 1914 was highest during the amaranthus period, as would be expected from a consideration of the intensity of the environmental factors. The mean maximum evaporation rate for the different periods during the hours near midday ranged from 700 to 900 gm. per hour from a tank of 6,540 sq. cm. in area.[1]

The highest temperatures and the greatest saturation deficits were encountered during the sorghum and amaranthus transpiration periods; yet these conditions produced no flattening of the peak of the transpiration curve of either plant, which is so marked in the case of wheat and rye. The lowest mean temperature and the smallest saturation deficit

[1] A loss of 1,000 gm. from the small tank corresponds to a loss of 0.0386 inch from the 8-foot tank referred to above, based on continuous records for the period, June 16 to September 19, 1914. The large tank loses more slowly during the forenoon, but more rapidly during the night. This is due to the heat capacity of the large tank. The records based on 24-hour periods show good agreement between the two tanks. To those who are more familiar with evaporation as measured by Livingston's atmometer, the following comparison with the shallow blackened evaporation tank used in our experiments will be of interest. The hourly evaporation graph of the porous-cup atmometers does not agree in form with the evaporation graph from the tank. The atmometers show a marked lag during the middle of the day as compared with the evaporation taking place from the tank. This might be anticipated, since the tank receives only the vertical component of the radiation, while the candle type of atmometer receives a smaller percentage of the total radiation at midday in midsummer than earlier or later in the day, due to the vertical walls. The difference is, however, very pronounced even with the new spherical form of porous cup. It is consequently impossible to establish a definite ratio between the evaporation from the Livingston atmometers and the shallow tank used in our experiments. The average ratio may, however, be given. From 6 a. m. to 6 p. m., on August 13 and 14, 1915, an evaporation of 1,000 c. c. from the tank corresponded to an evaporation of 6.5 c. c. from the white candle-type atmometers (1913); of 7.5 c. c. from the same type (1915); of 8.3 c. c. from the white, spherical type (1915); and of 10.9 c. c. from the black candle type (1915). The loss from the atmometers corresponding to 1,000 gm. loss from the shallow tank for different parts of the day is as follows:

Type of atmometer.	6 to 10 a. m.	10 a. m. to 2 p. m.	2 to 6 p. m.
White candle type (1913)	7.2	5.1	8.6
White candle type (1915)	8.2	5.8	10.0
White spherical type (1915)	9.1	6.7	10.3
Black candle type (1915)	14.0	8.4	12.9

During the night the atmometers each lost about 3 gm. of water, while the tank showed a slight gain due to deposition of dew. None of these atmometers had ever been used in other measurements, and distilled water was used in all cases. The values given are based on the means of determinations with four atmometers of each type, after the observed evaporation from each atmometer had been multiplied by the standardization coefficient supplied with the apparatus.

occurred during the oat transpiration period. This may account for the fact that the flattening of the transpiration curve of oats is not so marked as in the case of the other cereals.

The wind velocity during these experiments was higher during the daytime than during the night hours. There is a fairly well-defined maximum between 7 and 10 o'clock and another secondary maximum in the afternoon. Wind-still periods seldom occurred.

In Table XXXV are summarized the mean maximum values of the transpiration, evaporation, radiation, saturation deficit, and temperature for each period; and the yield, time of harvest, and the period during which transpiration measurements were made. The range in mean wind velocity and the mean maximum transpiration per gram of dry matter harvested have also been added to the table.

A comparison of the data for the three varieties of wheat shows a close agreement. Kharkov produced the highest yield and transpired at the highest rate. Kubanka produced the least dry matter and transpired at the lowest rate. On the basis of dry matter produced Kharkov transpired most rapidly and Kubanka least rapidly. From a consideration of unpublished data on the transpiration of cereals from seed time to harvest, these observations appear to have been taken during the period of maximum transpiration for the crops considered.

On the basis of transpiration throughout the total period of growth, the relative transpiration of Kharkov and Turkey wheat was the same—i. e., 365 ± 6 and 364 ± 6 gm. of water, respectively, for each gram of dry matter produced. Kubanka transpired relatively more—i. e., 394 ± 7 gm. of water for each gram of dry matter.

Oats transpired somewhat less rapidly than wheat in proportion to the amount of dry matter produced. A consideration of the temperature data shows the mean maximum temperature for the oat period to be about 7 degrees lower than for the wheat period. This difference in temperature and the resulting difference in humidity would be sufficient to account for the lower rate of transpiration of oats compared with wheat. On the basis of total transpiration, oats consumed 423 ± 5 gm. of water for each gram of dry matter produced, or 7 per cent more than Kubanka wheat.

Three different varieties of sorghum were used in the transpiration measurements—Minnesota Amber, milo, and Dwarf milo. The plants were apparently at the height of their transpiration during the measurements. The mean maximum transpiration rate of sorghum was higher in proportion to the dry matter harvested than for oats or wheat, but the physical conditions favored a more rapid transpiration during the sorghum period, as is shown by a comparison of the temperature, radiation, and saturation-deficit data. The slope of the sorghum transpiration curve near the peak is also much greater than for either wheat or oats.

The transpiration during the whole period of growth of sorghum, when based on dry matter produced, is practically the same for the three varieties here considered. Minnesota Amber transpired 239±2 gm. of water for each gram of dry matter produced; Dwarf milo, 273±4 gm.; and milo, 249±3 grams.

The transpiration rate of rye, when based on the dry matter harvested, is much higher than for any other crop included in the 1912 water-requirement measurements. This is due in part to the more extreme atmospheric conditions prevailing during this period and in part to the higher water requirement of rye, which is 39 per cent higher than Kubanka wheat and 15 per cent higher than Swedish Select oats.

The data presented during the long period for alfalfa were based on plants which yielded different amounts of dry matter. In order to make the comparison more exact, two short periods have been presented. The environmental conditions were somewhat more extreme during the early period, as is shown by a comparison of radiation, temperature, and saturation deficit. The evaporation rate was also higher. On the basis of dry matter harvested, the transpiration during the two periods was the same. It is necessary in this connection to consider the size of the plant at the actual time of the measurements. The late-period crop was harvested 6 days after the period when the transpiration measurements were made, while the early-period crop was harvested 20 days after the termination of the transpiration measurements. It is evident, therefore, that the ratio of transpiration rate to dry matter of the early-period crop would have been considerably higher had this crop been harvested soon after the transpiration measurements were completed.

The most severe environmental conditions in 1914 were encountered during the amaranthus period. Solar radiation was greater and saturation deficit, air temperature, and evaporation higher. On the basis of dry matter, amaranthus transpired less than alfalfa, but more than rye. On the basis of the whole period of growth, the water requirement of amaranthus was much less than rye, the higher rate of transpiration shown in the data here presented being due to the unusually severe conditions prevailing during this period.

While the writers are considering the data in this paper primarily from the standpoint of the relative transpiration rate of the different plants and are not particularly concerned with absolute values, it is interesting to find that the data here presented conform as nearly as can be expected to the relative transpiration rates of the different plants as determined from the water-requirement measurements.

COMPARISON OF THE FORM OF THE CURVES

In order that a more accurate comparison may be made between the form of the transpiration graph and that of the several environmental factors, the mean hourly values presented in the preceding tables have

also been expressed in terms of percentage of the maximum. In the case of temperature and wet-bulb depression, the calculation has been based on the maximum range—i. e., the mean minimum is taken as zero on the scale. The data for the various crops reduced to this uniform basis are presented in figures 9 to 15, inclusive, the axis of abscissas representing time and the axis of ordinates the percentage of the mean daily maximum (or mean daily range).

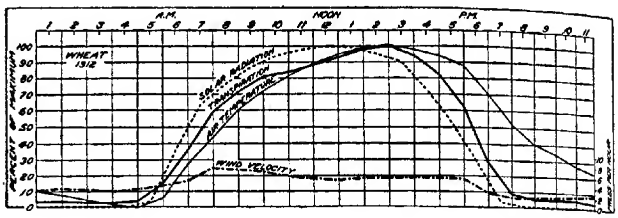

FIG. 9.—Graphs showing transpiration of wheat and the hourly values of cyclic environmental factors, all plotted in percentage of the maximum or maximum range.

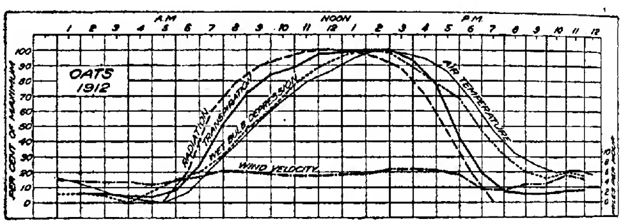

FIG. 10.—Graphs showing the hourly transpiration of oats and the hourly values of the cyclic environmental factors, all plotted in percentage of the maximum or maximum range.

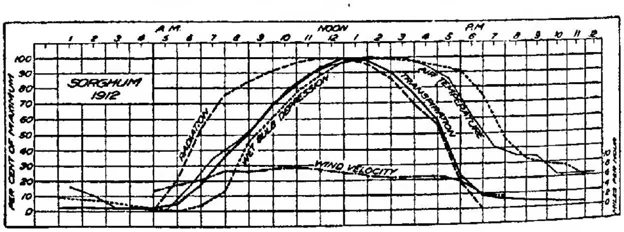

FIG. 11.—Graphs showing the hourly transpiration of sorghum and the hourly values of cyclic environmental factors, all plotted in percentage of the maximum or maximum range.

An inspection of the charts will show that the radiation graph rises in advance of the other cyclic environmental factors. This is to be expected, since the change in radiation is the primary cause of the cyclic change of the other components. For the same reason the radiation also rises in advance of the transpiration and falls either in advance of it, as in

the case of the three cereals wheat, oats, and rye, or approximately with the transpiration, as in the case of sorghum, alfalfa, and amaranthus.

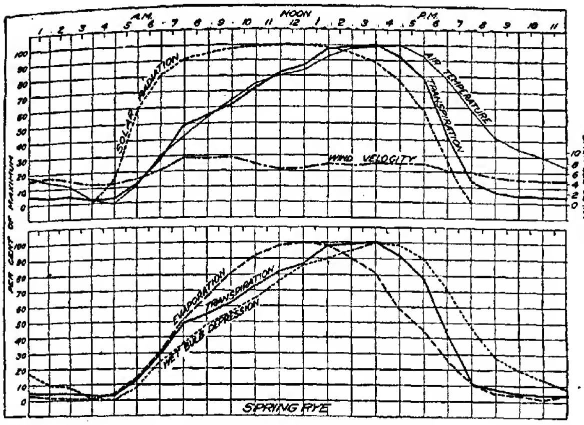

FIG. 12.—Graphs showing hourly transpiration of spring rye and the hourly values of the cyclic environmental factors, all plotted in percentage of the maximum or maximum range.

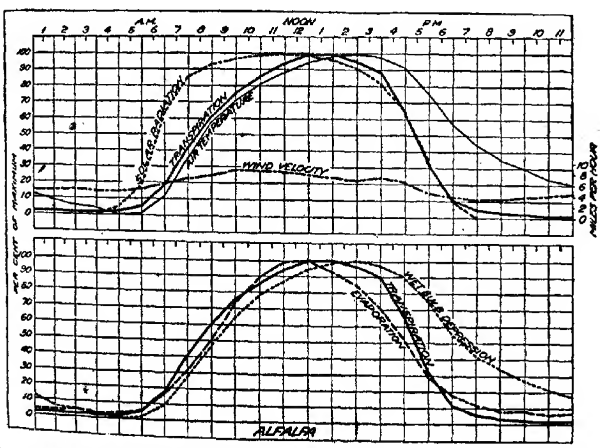

FIG. 13.—Graphs showing the hourly transpiration of alfalfa and the hourly values of cyclic environmental factors, all plotted in percentage of the maximum or maximum range.

This is clearly shown in figure 16, in which the two graphs are plotted for each plant.

The transpiration rises in advance of the temperature in the case of wheat, oats, and alfalfa; approximately with the temperature for rye

and sorghum; and later than the temperature for amaranthus. This is in evidence in figure 17, in which these two graphs alone are plotted for each plant measured. The transpiration in the afternoon always falls off far more rapidly than the temperature, and when the transpiration has reached the night level the temperature is still above the minimum by an amount corresponding roughly to one-third the daily range.

The wet-bulb depression and the air-temperature curves are very similar in form, owing to the fact that with a uniform absolute-moisture content of the air the former curve is determined strictly by the latter.

The transpiration rises in advance of the wet-bulb depression (fig. 18) in every instance except amaranthus, in which the graph starts later but crosses the wet-bulb depression curve about 9 a. m. The transpiration falls more rapidly than the wet-bulb depression in every instance.

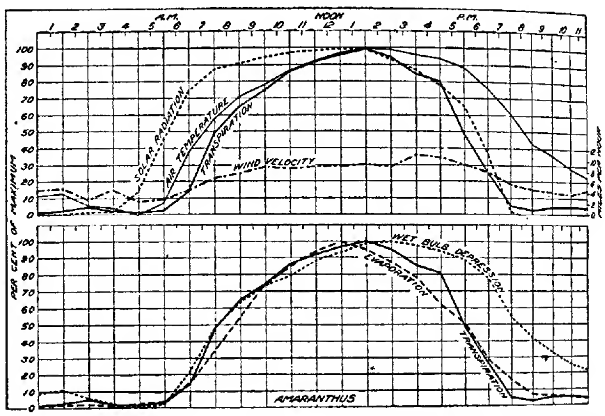

FIG. 14.—Graphs showing the hourly transpiration of *Amaranthus retroflexus* and the hourly values of the cyclic environmental factors, all plotted in percentage of the maximum or maximum range.

The evaporation rises later than the transpiration graph (fig. 19) in the case of alfalfa and amaranthus, owing to the fact that the tank evaporation is determined largely by the vertical component of the radiation, while isolated pots of plants probably receive radiation in excess of the vertical component. In the case of rye, the two graphs coincide during the early morning hours, but a marked depression of the transpiration curve from the evaporation graph occurs at 8 a. m., this difference persisting until after the evaporation graph has passed its maximum. The comparison of the two graphs brings out very strikingly the depression in the transpiration graph of rye during the morning hours, to which attention has already been called and which is a common feature of the cereals so far investigated.

The evaporation graph in the early afternoon falls in advance of the transpiration graphs, but owing to the greater slope of the transpiration

graphs in the late afternoon the two curves tend to reach the night level at about the same time.

DISTRIBUTION OF TRANSPIRATION IN RELATION TO SOLAR RADIATION

In Table XXXVI is given a summary of the data represented by the radiation and transpiration graphs shown in figure 16. The second column of this table shows the relative radiation received by the different

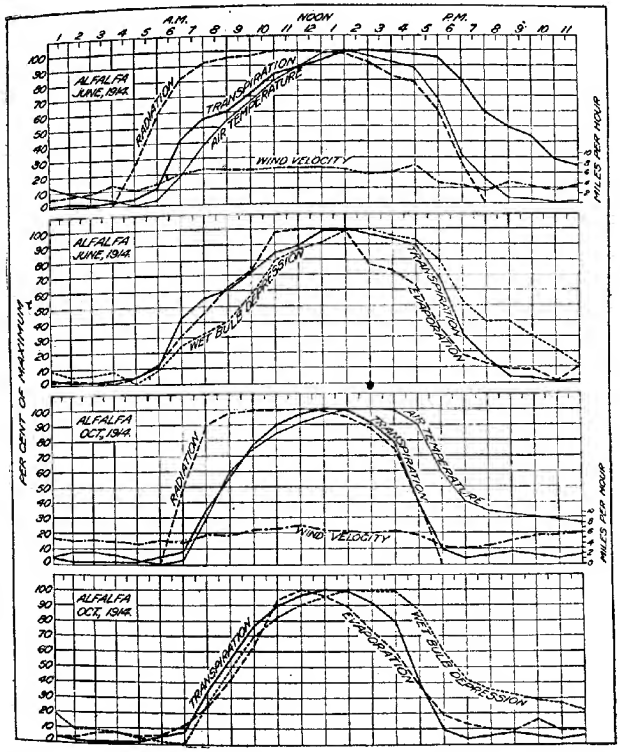

FIG. 15.—Graphs showing the hourly transpiration values of alfalfa for short periods in June and in October, with the hourly values of the cyclic environmental factors, all plotted in percentage of the maximum or maximum range.

crops, giving in arbitrary units the integrated area bounded by the radiation curve and the time axis. The integrated transpiration obtained in a similar manner is given in the third column. In the fourth column is given the ratio of the integrated transpiration to the integrated radiation for each particular crop.

It will be seen from these figures that the integrated transpiration for wheat and oats slightly exceeds the integrated radiation and that the reverse is true for rye, sorghum, amaranthus, and alfalfa. The transpiration curves for sorghum, amaranthus, and alfalfa lie almost wholly within the radiation curve. The ratio of the transpiration area to the radiation area is also low in the case of spring rye, owing to the comparatively low rate of transpiration during the morning hours.

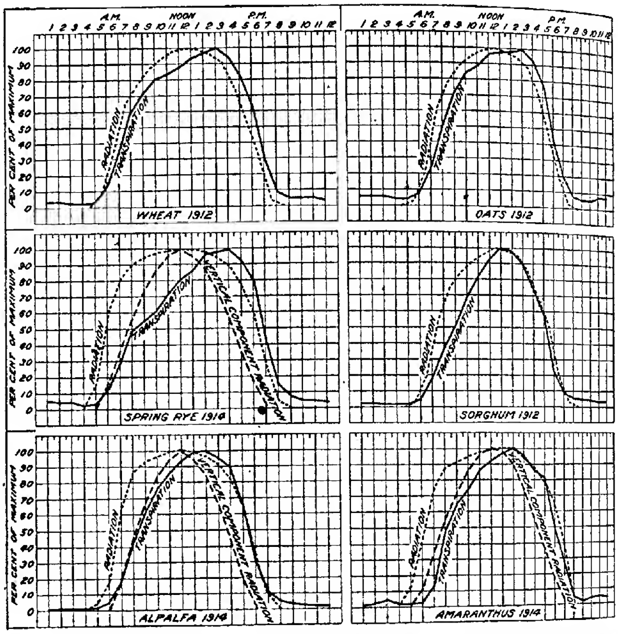

FIG. 16.—Comparison of the form of transpiration graphs with the graphs representing the total radiation and the vertical component of the radiation.

TABLE XXXVI.—*A comparison of radiation and transpiration based on the area inclosed by the graphs in figure 17*

Plant.	Area bounded by—		Ratio of transpiration to radiation area.	Transpiration.					
	Radiation graph.	Transpiration graph.		Area for daylight hours.	Daylight.	Night.	A. M.	P. M.	11 a. m. to 3 p. m.
					Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Wheat	302	310	1.03	298	96	4	44	56	37
Oats	289	303	1.05	286	94	6	44	56	39
Rye	357	306	.86	290	95	5	38	62	36
Sorghum	283	253	.89	240	95	5	43	57	45
Amaranthus	346	284	.82	275	97	3	42	58	40
Alfalfa	315	271	.86	264	97	3	44	56	43

The last portion of Table XXXVI gives the relative transpiration for different parts of the day. The percentage of the transpiration taking place during daylight is very uniform, ranging from 94 per cent for oats to 97 per cent for amaranthus and alfalfa. The transpiration during the night is remarkably low, ranging from 3 per cent for amaranthus and alfalfa to 6 per cent for oats. The data as presented represent the integration of the transpiration and radiation for hourly intervals, so that the transpiration for the hour interval during which sunrise (or sunset) occurred has been included as daylight transpiration. The ratio can be more accurately determined from the automatic records, which show an

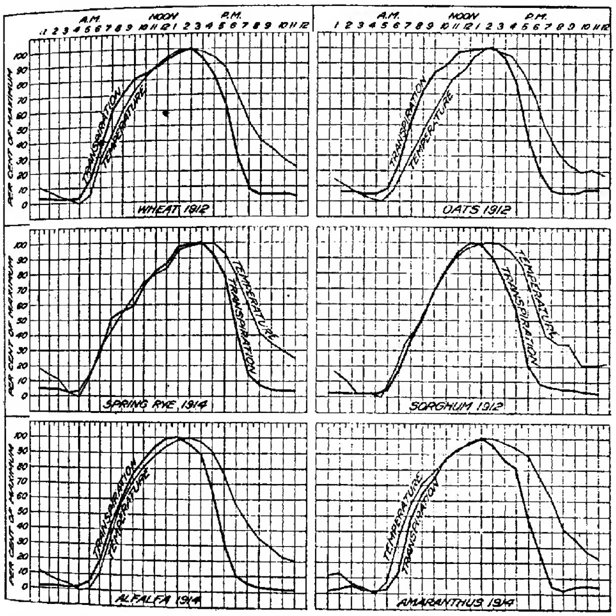

FIG. 17.—Comparison of the transpiration graphs plotted in percentage of the maximum with the temperature graphs plotted in percentage of the maximum range.

average night transpiration less than 5 per cent of that occurring during daylight. This low night transpiration is significant when we consider that the temperature and the saturation deficit are relatively high during the early hours of the night and that the dew point is seldom reached at Akron. The wind velocity at night is also at least one-half the average daylight velocity.

It will be seen from Table XXXVI that the transpiration in the forenoon is lower than in the afternoon, the difference being greatest in the case of rye and least in the case of wheat, oats, and alfalfa. For the

group of plants as a whole, 43 per cent of the transpiration took place before noon and 57 per cent in the afternoon, while the average radiation during the period was slightly greater in the forenoon.

In the last column of the table is given the percentage of transpiration taking place between 11 a. m. and 3 p. m. While these figures are not directly comparable, owing to the difference in the length of the day—i. e., in the number of daylight hours— it is clear that from one-third to

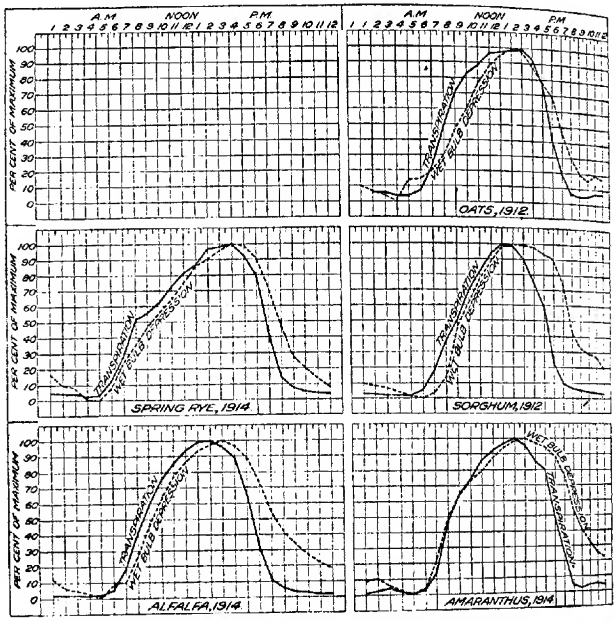

Fig. 18.—Comparison of transpiration with wet-bulb depression, both plotted in percentage of the maximum range.

one-half of the transpiration during the 24-hour period takes place from 11 a. m. to 3 p. m.

RATIO OF TRANSPIRATION TO EVAPORATION

Transpiration is often regarded as evaporation modified to some extent by plant structures and plant functions. Both are influenced by radiation, temperature, saturation deficit, and wind. Because of the similarity of the two processes, the evaporation rate has often been used as a standard to which the transpiration is referred.

Livingston (1906 and 1913) has given special attention to the relation of transpiration to evaporation, and has applied the terms "relative

transpiration," "transpiring power" (Livingston and Hawkins, 1915), to the ratio of the transpiration rate to the evaporation rate of his porous-cup atmometer. It has been shown [1] that the graphs representing transpiration and the evaporation from the porous-cup atmometer are similar in form, but that their maxima do not as a rule occur at the same time in plants exposed to extreme conditions. Furthermore, when the

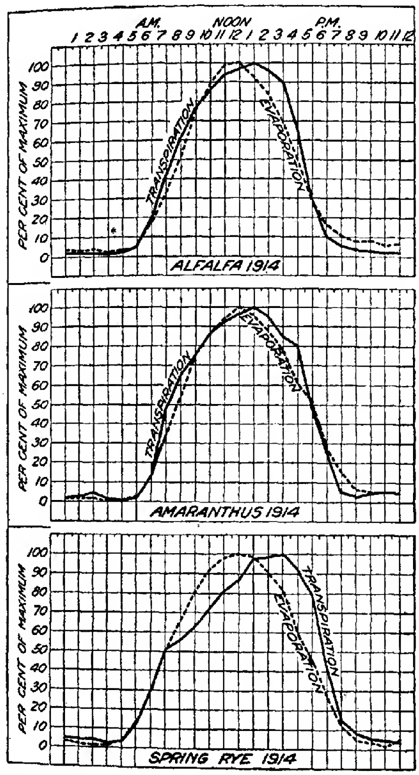

FIG. 19.—Comparison of the transpiration with the evaporation from a free-water surface in a shallow, blackened tank, both plotted in percentage of the maximum range.

ratio of the transpiration to evaporation (the relative transpiration) is plotted against time, the daily graph usually shows two maxima, one in the morning and a second in the afternoon.

Graphs representing the ratio of the transpiration rate of rye, alfalfa, and amaranthus to the evaporation rate are given in figure 20 and show

[1] See also Shreve, 1914; Bakke, 1914.

the maxima referred to in the investigations cited. One maximum occurs in the morning about 7 or 8 o'clock, and a second and greater maximum is found in the afternoon between 4 and 6 p. m.[1] In other words, the transpiration graph shows a tendency to rise earlier in the morning and fall later in the afternoon than the evaporation graph. This is evident in each of the three graphs presented in figure 20.

This result is capable of two quite dissimilar interpretations. If the assumption is made that evaporation constitutes a correct summation of the influence of environment on transpiration, it follows logically that the departure of the transpiration-evaporation ratio from a constant value is due to a decrease or increase in the transpiration coefficient. It must,

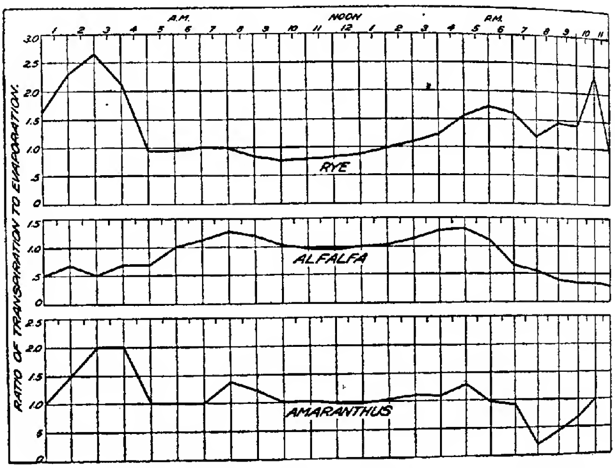

FIG. 20.—Graphs showing hourly ratio of transpiration to evaporation as plotted in figure 19.

however, be recognized that all evaporimeters do not respond to their environment in the same way. A large deep tank does not have the same daily graph as a shallow tank. A filter-paper evaporimeter does not follow the graph of the porous-cup atmometer. If none of these agree, can it be said without further proof that the evaporation rate of any one of them is proportional to the transpiration rate of a plant which responds *freely* to its environment? The fact that the transpiration graph is so uniformly asymmetrical with respect to noon in our determinations and that the evaporation graph is so uniformly symmetrical would indicate that the two processes were not controlled in the same way by the physical factors of the environment. The writers are inclined to the belief that

[1] The hourly values of transpiration and evaporation at night are so small that the observational errors make the ratio uncertain, and the night ratios will consequently not be considered at this time.

the departure of the transpiration from evaporation should not be taken as proof of a change in the transpiration coefficient of the plant and that it is safer for the present not to base conclusions on this assumption but instead to consider directly the factors which influence both transpiration and evaporation.

CORRELATION BETWEEN TRANSPIRATION AND ENVIRONMENTAL FACTORS

Two methods have been employed by the writers in making a quantitative investigation of the relationships existing between the transpiration of the plant and the intensity of its environment: (1) The coefficient of correlation between the transpiration and a given environmental factor has been computed as a basis for the determination of the relative influence of the various environmental factors and (2) the relationship between the mean hourly transpiration and the hourly values of the several environmental factors has been computed by the method of least squares, and the relative weights of the different environmental factors determined from the coefficients of the resulting equation. Such a reduction of the data appears highly desirable, for it affords a means of comparison independent of the personal element. The results of the correlation reductions will first be considered.

In computing the correlation coefficients,[1] the individual hourly observations as presented in Tables I to XXVI were used. The data in each instance embrace not less than three days' observations with the transpiration measurements in duplicate, so that the number of pairs of terms—i. e., the "population" considered—approximated 144 for the 3-day periods in the transpiration correlations and in other cases exceeded this number.

The correlation coefficients of the transpiration rate of alfalfa, amaranthus, and rye, with the intensity of the several environmental factors, are presented in Table XXXVII, together with the probable error of the correlation coefficient in each case.

[1] For a presentation of the theory and the method of computing correlation coefficients, see Yule (1912) and Davenport (1907).

TABLE XXXVII.—*Correlation between transpiration and environmental factors*

Plant, period, and components.	Correlation coefficient.	Plant, period, and components.	Correlation coefficient.
Alfalfa (long period, Sept. 10 to Oct. 20, 1914):		Alfalfa (June 18, 19, 21, 1914)—Continued.	
Radiation and transpiration	0.840±0.009	Wind velocity and transpiration	0.626±0.036
Temperature and transpiration	.819± .011	Wind velocity and radiation	.641± .046
Wet-bulb and transpiration	.822± .011	Vertical radiation and transpiration	.818± .013
Evaporation and transpiration	.838± .011	Amaranthus (July 7 to 9, 1914):	
Wind velocity and transpiration	.485± .026	Radiation and transpiration	.844± .016
Wind velocity and radiation	.302± .030	Temperature and transpiration	.849± .016
Alfalfa (Oct. 16 to 20, 1914):		Wet-bulb and transpiration	.842± .016
Radiation and transpiration	.886± .010	Evaporation and transpiration	.946± .006
Temperature and transpiration	.859± .012	Wind velocity and transpiration	.683± .031
Wet-bulb and transpiration	.843± .013	Wind velocity and radiation	.776± .032
Evaporation and transpiration	.929± .006	Vertical radiation and transpiration	.863± .014
Wind velocity and transpiration	.353± .039	Rye (June 22 to July 3, 1914):	
Wind velocity and radiation	.275± .084	Radiation and transpiration	.820± .014
Vertical radiation and transpiration	.862± .011	Temperature and transpiration	.854± .011
Alfalfa (June 18, 19, 21, 1914):		Wet-bulb and transpiration	.748± .018
Radiation and transpiration	.861± .015	Evaporation and transpiration	.894± .033
Temperature and transpiration	.788± .021	Wind velocity and transpiration	.376± .036
Wet-bulb and transpiration	.852± .008	Wind velocity and radiation	.353± .047
Evaporation and transpiration	.888± .012	Vertical radiation and transpiration	.766± .017

An inspection of the correlation table will show that, excluding evaporation, the highest correlation is obtained between radiation and transpiration. The correlation coefficient for these components is remarkably uniform for the different crops and periods, ranging from 0.82 to 0.88, the lowest value occurring in the case of rye, as one might expect from the form of the transpiration graph.

The similarity in the form of the composite graphs for air temperature and wet-bulb depression would lead to the expectation that their correlation coefficients with transpiration would be similar and the coefficients are in fact nearly the same. The only exceptions are (1) alfalfa (June period), in which the wet-bulb depression shows the higher correlation with transpiration; and (2) rye, in which temperature is the more closely

correlated. Reference to figures 12 and 17 shows the unusually close agreement between the composite transpiration graph for rye and the temperature graph.

The correlation coefficient of temperature (or wet-bulb depression) and transpiration also agrees approximately with that of radiation and transpiration. In other words, it appears from a consideration of these coefficients that radiation, temperature, and wet-bulb depression show an equally close association with the daily transpiration cycle. The correlation of temperature and wet-bulb depression with transpiration may, however, be looked upon as being in part associative with radiation rather than causative, as will appear from the following considerations.

The degree of correlation[1] between radiation and transpiration (from 0.82 to 0.88) indicates that the radiation determines the transpiration to the extent of from 0.67 to 0.77, the square of the correlation coefficients, if radiation is regarded as the primary causative factor. The remainder (0.33 to 0.23) is to be ascribed to other factors. If temperature is taken as a causative factor of transpiration, the correlation coefficients show a dependence of transpiration upon temperature of from 0.62 to 0.74; but this is far in excess of the remainder (0.33 to 0.23) to be accounted for. In other words, the sum of the squares of the two correlation coefficients is in excess of unity. This means, then, that temperature and radiation are intercorrelated. A similar intercorrelation exists between radiation and wet-bulb depression, and an exact differentiation is impossible. However, since these factors are physically dependent upon radiation, we may assign to radiation the total effect indicated by the correlation coefficient, keeping always clearly in mind the assumption involved. On this basis the radiation intensity determines two-thirds to three-fourths of the transpiration at Akron on clear days; or all other factors combined have only from one-third to one-half the influence of radiation.

On the other hand, if it is preferred to look upon radiation, temperature, and wet-bulb depression as direct independent causative factors (which must also be recognized as involving a specific assumption to this effect), then it is evident from Table XXXVII that these factors play approximately an equal part in determining transpiration on clear days. Not only are the correlation coefficients very nearly the same for the different factors with a given crop, but they vary but slightly for the different plants investigated.

[1] While a correlation coefficient of unity denotes perfect correlation, a correlation coefficient of less than mity must not be interpreted as determining the relationship in proportion to the magnitude of the correlaion coefficient, for even in the case of a primary causative factor the relationship can not be greater than the quare of the correlation coefficient. For example, a correlation coefficient of 0.707 between a causative nd a resultant term indicates a dependence of the latter upon the former of 0.5—i. e., the square of 0.707. This may be easily demonstrated by computing the correlation coefficient between either of two series of umbers, each having a normal frequency distribution, with the product of one series by the other. The orrelation coefficient of the product series with either primary series will be found to be 0.707. In other words, each series determines the product series to the extent of 0.5, while the two series together determine he product series absolutely.

In order to decide between these two assumptions, other evidence is necessary; and this may be found in a consideration of the transpiration during the night—i. e., when the radiation received by the plants is nil.

In Table XXXVIII are summarized the transpiration and wet-bulb depression (in percentage of the maximum) and the air temperature (in percentage of the maximum range) for the hours 3 to 4 a. m. and 8 to 9 p. m. It is evident from the table that a simultaneous diminution in the wet-bulb depression of one-fourth of its maximum and in temperature of one-third of its maximum range results in a drop of only 3 per cent in the transpiration rate. This would seem to indicate that the high correlation obtained between transpiration and air temperature (or wet-bulb depression) is largely due to the direct correlation between radiation and temperature (or wet-bulb depression).[1]

TABLE XXXVIII.—*Comparison of transpiration, temperature, and wet-bulb depression at 3 to 4 a. m. and 8 to 9 p. m.*

Crop or period.	Per cent of maximum transpiration.			Per cent of maximum temperature.			Per cent of maximum wet-bulb depression.		
	3 to 4 a. m.	8 to 9 p. m.	Difference in a. m. and p. m. reading.	3 to 4 a. m.	8 to 9 p. m.	Difference in a. m. and p. m. reading.	3 to 4 a. m.	8 to 9 p. m.	Difference in a. m. and p. m. reading.
Wheat	3	5	2	3	40	37	.....	.....	.....
Oats	4	6	2	2	24	22	21	37	16
Rye	3	7	4	3	42	39	17	39	22
Sorghum	2	5	3	2	34	32	25	48	23
Amaranthus	1	3	2	4	42	38	12	45	33
Alfalfa	2	3	1	4	35	31	15	42	27
June period	2	3	1	3	49	46	19	47	28
October period	1	7	6	5	32	27	2	38	36
Mean	.....	.....	3	.....	.....	34	.....	.....	26

If we ascribe to radiation a causative effect equal to that indicated by the correlation coefficient with transpiration, it becomes possible also to investigate the influence of wind velocity on transpiration by a process of elimination similar to that employed above.

Transpiration in still air is somewhat less than in moving air, since the latter tends to reduce the distance that the transpired moisture must move in order to find free-air conditions. In other words, the wind tends to increase the diffusion gradient, and so increases the transpiration (or evaporation) rate. But a slight movement appears to satisfy this condition, and the correlation coefficients between wind and transpiration (Table XXXVII) show that the variation in wind at Akron, where some wind nearly always occurs, has little influence on the trans-

[1] In opposition to this view it may be argued that the plants from 3 to 4 a. m. are more turgid than from 8 to 9 p. m. This is undoubtedly true, but it is also true that during the last named period the plants are more turgid than at 2 or 3 p. m., the period during which the maximum transpiration rate was observed.

piration rate. In arriving at this conclusion it is again necessary to consider the correlation not only between wind and transpiration, but also between wind and radiation. If the wind influences transpiration independently of its association with radiation, the wind velocity must show a higher correlation with transpiration than with radiation. This occurs only during the long alfalfa period, in which there appears to be a slight effect due to wind. In all other cases the wind correlation with transpiration differs from the wind correlation with radiation by an amount not greater than the probable error of the difference. Here, again, we are making the specific assumption that the radiation is the primary causative factor, so that if wind is associated with transpiration to an extent no greater than with radiation its effect on transpiration is slight. This assumption is here again supported by the fact that the transpiration is extremely low during the night hours, although the wind is blowing.

If transpiration and evaporation are largely determined by the same factors or, in other words, if transpiration is essentially a physical process, then a high correlation between transpiration and evaporation is to be expected. Reference to Table XXXVII will show that the correlation of evaporation with transpiration ranges from 0.84 to 0.95. The latter value is slightly higher than the maximum correlation (0.89) of radiation with transpiration and shows that 0.9 of the transpiration was in this instance determined by the same factors which determined the transpiration.

The relation of evaporation to transpiration is to be considered as associative rather than causative, both responding to the same environmental factors, but not necessarily in precisely the same way or to the same degree. The extent of this association furthermore depends upon the manner in which evaporation is measured. For example, the evaporation rate from a free-water surface in a very shallow tank conforms much more closely to the transpiration rate than when a deep tank is used, since the latter, on account of its large heat capacity, stores up a large amount of energy which is dissipated through evaporation during the night. It is evident that the evaporimeter must simulate the plant system as nearly as possible in absorption and heat capacity if a high degree of correlation between the two is to be attained.

LEAST-SQUARE RELATIONSHIPS BETWEEN TRANSPIRATION (OR EVAPORATION) AND ENVIRONMENTAL FACTORS

The method of least squares affords a means of determining the relative influence of the various environmental factors upon the transpiration. In these least-square reductions (Merriman, 1893, and Bartlett, 1915) the mean hourly values have been used, and it has been assumed that the relationship is linear in character—i. e., that the transpiration varies directly in proportion to the intensity of the environmental factors.

The results of the least-square reductions are presented graphically in figures 21 and 22. In all cases, the vertical component of the radiation has been employed rather than the radiation on a surface normal to the sun's rays. The reason for this will be apparent from an inspection of the radiation and transpiration charts, where it will be seen that during the early morning hours the slope of the radiation graph is much greater than that of the transpiration graph for rye, alfalfa, and amaranthus. In other words, the transpiration rate does not increase nearly as rapidly as the normal component of the radiation during the early daylight hours. In a field of grain or alfalfa, considered as a whole, it is evident that the vertical component of the radiation would alone be effective. In the case of an isolated pot of plants standing on the transpiration scale, the horizontal component would also be effective. The extent to which this enters can not be directly determined, however, and in the following discussion the vertical component has been used throughout.[1]

TRANSPIRATION AS DETERMINED BY RADIATION AND TEMPERATURE

The observed and computed transpiration graphs, the latter based on the assumption that the vertical component of the radiation and the air temperature are the primary controlling factors in transpiration, are given in figure 21. The computed equations are as follows:

For rye.......................... $0.384\ R_v + 0.642\ \theta = T$;
For alfalfa...................... $0.514\ R_v + 0.539\ \theta = T$;
For amaranthus.................. $0.546\ R_v + 0.443\ \theta = T$;

in which

R_v is the vertical component of radiation,
θ is the temperature rise, and
T is the transpiration.

In the above equations and in those which follow the hourly values for each term are expressed as a percentage of the maximum. In other words, the general dimensionless equation is of the form:

$$a\frac{R'_v}{R'_{v_{max}}} + b\frac{\theta' - \theta'_0}{\theta'_{max} - \theta'_0} = \frac{T'}{T'_{max}}$$

in which the primed quantities represent observed values.

[1] *Calculation of the vertical component of radiation.*—If R represents the normal component of the radiation of the sun, R_v the vertical component, and h the altitude—i. e., the angular distance of the sun above the horizon—then: $R_v = R \sin h$.

Expressing the altitude in terms of declination and hour angle (Smithsonian Institution, 1894, p. lxviii), we have $\sin h = \sin \phi \sin \delta + \cos \phi \cos \delta \cos t$,
in which

ϕ = the latitude of the place of observation;
δ = the declination of the sun—i. e., the angular distance above or below the Equator (from U. S. Navy Dept., 1912); and
t = the hour angle—i. e., the angle between the meridian plane through the place and the meridian plane through the sun.

Substituting, we have:
$R_v = R (\sin \phi \sin \delta + \cos \phi \cos \delta \cos t)$.

The daily observations are expressed on the basis of mean sun time, which introduces a slight error in the calculation of the vertical radiation component.

An inspection of the curves in figure 21 will show that the computed graph agrees with the observed transpiration graph much better in the morning than in the afternoon.[1] The computed graph always reaches its maximum in advance of the observed graph. The greater departures occur during the early afternoon and early evening. The agreement is by no means as good as is to be desired, and the graphs show clearly that transpiration can not be completely accounted for on the assumption

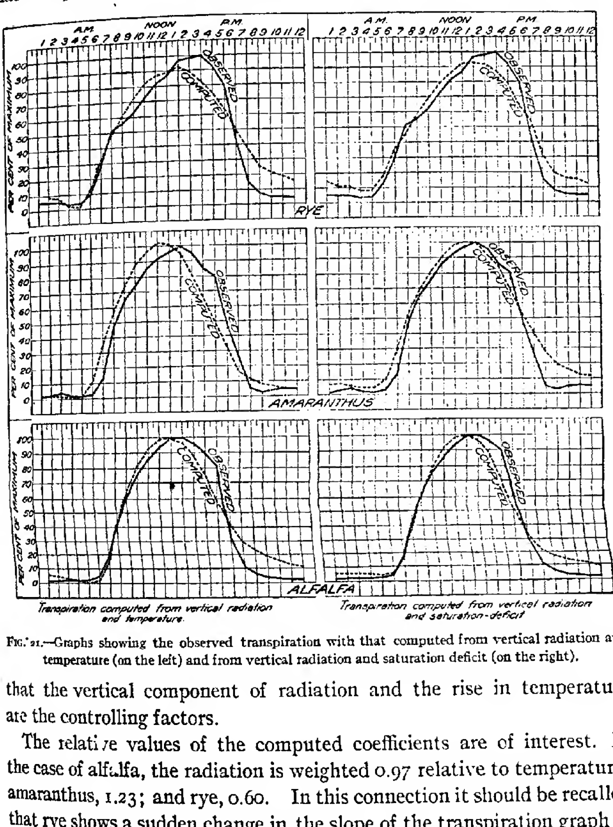

FIG. 21.—Graphs showing the observed transpiration with that computed from vertical radiation and temperature (on the left) and from vertical radiation and saturation deficit (on the right).

that the vertical component of radiation and the rise in temperature are the controlling factors.

The relative values of the computed coefficients are of interest. In the case of alfalfa, the radiation is weighted 0.97 relative to temperature; amaranthus, 1.23; and rye, 0.60. In this connection it should be recalled that rye shows a sudden change in the slope of the transpiration graph in the morning, differing markedly from alfalfa and amaranthus in this respect.

[1] Since preparing figures 21 and 22 a recalculation based on more exact determinations of the vertical component of radiation has given computed values of transpiration and evaporation which are in somewhat closer agreement with the observed values during the daylight hours than those indicated in the charts. The coefficients in the equations are based upon the revised calculation.

TRANSPIRATION AS DETERMINED BY RADIATION AND SATURATION DEFICIT

Corresponding graphs based upon vertical radiation and saturation deficit are also given in figure 21. The values for the latter term are computed from the mean hourly wet-bulb depression and the corresponding hourly air temperatures. The resulting equations follow:

For rye . . . . $0.455\ R_v+0.622\ D=T$;
For alfalfa. . . . . $0.538\ R_v+0.553\ D=T$;
For amaranthus. . . . . $0.538\ R_v+0.481\ D=T$;

in which D represents the saturation deficit expressed as a percentage of

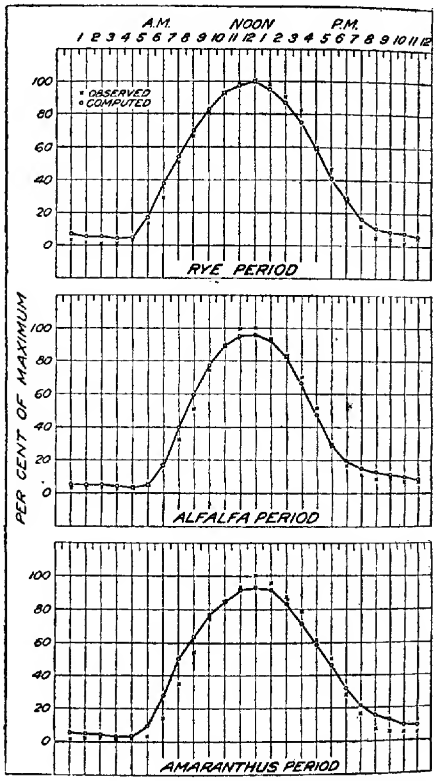

FIG. 22.—Graphs showing the observed evaporation with that computed by least-square methods from the vertical component of radiation and the saturation deficit.

the maximum, and the other symbols have the same meaning as before. An inspection of the graphs shows them to be similar in form to those computed from radiation and temperature. The coefficients are also

similar to those of the former series. The ratio of the radiation to the saturation-deficit coefficient for the different plants is as follows: Rye, 0.73; alfalfa, 0.97; amaranthus, 1.12. The equation for rye again shows the radiation to have the lesser influence of the two factors considered, while in the case of the other two plants, the radiation has an equal or greater influence. The equations for the latter plants are in fair agreement, but in all cases discrepancies occur between the observed and computed curves, particularly during the early afternoon and early evening hours.

EVAPORATION AS DETERMINED BY RADIATION AND SATURATION DEFICIT

The evaporation rate from the shallow, blackened tank for the three transpiration periods just considered has also been computed, assuming the vertical radiation and the saturation deficit to be the controlling environmental factors. The observed and computed evaporation graphs are given in figure 22. The agreement during the rye and alfalfa periods is very satisfactory, but during the amaranthus period the departures are greater. The evaporation equations for the several periods are as follows:

Rye period. $0.787\ R_v + 0.292\ D = E$;
Alfalfa period. . . . . $0.680\ R_v + 0.360\ D = E$;
Amaranthus period. . . . . $0.563\ R_v + 0.411\ D = E$;

in which E represents the evaporation expressed as a percentage of the maximum.

It will be observed that the radiation has a preponderating influence in each instance.

DISCUSSION OF LEAST-SQUARE REDUCTIONS

The least-square reductions again emphasize the fact that the transpiration response to changing environmental conditions is not the same for different plants. In other words, the distribution of the transpiration loss through the day varies with different plants. Furthermore, the distribution of the transpiration loss differs from the distribution of the evaporation loss from a shallow tank. As a whole, the agreement between observed and computed evaporation is much closer than between observed and computed transpiration. Either some factor operative in transpiration yet remains to be accounted for or the transpiration system changes its coefficient during the day. The latter condition may result from stomatal control or through the inability of the plant to secure sufficient water to maintain complete turgidity during the day. The fact that the evaporation on clear days can be satisfactorily accounted for from a consideration of radiation and saturation deficit indicates that the essential environmental factors have been considered and suggests that the outstanding differences between observed and computed trans-

piration are due to differences in the plants or to some change in the plant as the day progresses.

It is probable that plants differ also in their response to solar energy, the absorption coefficient of different plants not being the same, while the dissipation of the energy absorbed is quite different in different plants. In other words, the ratio of the energy dissipated through transpiration and lost by the plant through emissivity is not the same for all species. Such changes probably occur also in the same plant during the daily cycle, which would modify the transpiration coefficient irrespective of the changes in physical conditions.

SUMMARY

This paper deals with measurements of transpiration on clear days at Akron, Colo., in relation to environmental factors. The plants, which included wheat, oats, rye, sorghum, alfalfa, and amaranthus, were grown in large sealed pots of the type used in water-requirement measurements, containing sufficient soil (about 115 kgm.) to enable the plants to make a normal growth. The transpiration was determined by weighing, four automatic platform scales recording each 20-gm. loss being used for the purpose. Automatic records were simultaneously made of the radiation intensity, the air temperature, the depression of the wet-bulb thermometer, the evaporation, and the wind velocity. The radiation intensity and the wet-bulb depression were measured by differential telethermographs, and the evaporation rate from a free-water surface was determined by mounting a shallow, blackened evaporation tank 3 feet in diameter on an automatic platform scale.

Composite graphs are presented, showing the mean hourly transpiration rate for each of the plants considered, together with the mean hourly values of the radiation, air temperature, wet-bulb depression, and wind velocity for the transpiration period and also the mean hourly evaporation rate. On the basis of the form of the curves the transpiration graphs may be grouped into two classes having characteristic features. The cereals show a marked change in the slope of the transpiration graph in the forenoon unaccompanied by corresponding changes in the environmental factors. On the other hand, the forage plants and amaranthus give little or no indication of such a change. This flattening of the graphs in the case of the cereals appears to be due to some change in the plant, resulting in a reduction in the transpiration rate below what would be expected from the form of the curve during the early morning hours.

The hourly transpiration rate of the cereals on clear days increased steadily, though not uniformly, from sunrise to a maximum value, usually reached between 2 and 4 p. m., after which it fell rapidly to the night level. The transpiration graphs for sorghum, alfalfa, and amaranthus were somewhat more symmetrical with respect to midday, reaching

heir maximum between noon and 2 p. m., after which they fell approximately with the radiation.

The transpiration during the night at Akron is very low, being only 3 to 5 per cent of the transpiration during the daylight hours.

The radiation graphs are practically symmetrical with respect to noon, showing that the days selected were relatively clear. When all the mean hourly values are expressed as a percentage of the maximum, the radiation intensity rises in advance of the transpiration (and in advance of all the other environmental factors as well) and falls either in advance of the transpiration or with it, depending on the plant considered. Radiation then may be looked upon as the primary causative factor in the cyclic changes.

The air temperature and wet-bulb depression graphs are very similar in form, since the latter can be determined from the former on days in which the absolute humidity of the air is not changing. The transpiration graphs usually rise and always fall in advance of air temperature.

The evaporation graph from the shallow, blackened tank (water approximately 1 cm. in depth) is similar in form to the graph representing the vertical component of radiation. This is to be expected, since only the vertical component would strike the horizontal water surface. The evaporation graph rises and falls with, or slightly later than, the vertical component of radiation.

Computation of the correlation coefficients between transpiration and the various environmental factors shows the radiation, air-temperature, and wet-bulb depression to be correlated with transpiration approximately to the same degree. The correlation coefficients of transpiration with radiation range from 0.82 to 0.89; with temperature from 0.77 to 0.86; and with wet-bulb depression, from 0.75 to 0.85. These figures show the intercorrelations existing among the environmental factors, since the sum of the squares of the coefficients of independent causative factors influencing transpiration can not exceed unity. If radiation is taken as the primary causative factor, the correlation coefficients show that 0.67 to 0.77 of the transpiration on clear days under Akron conditions is determined by the radiation intensity.

If the environmental factors are considered as independent, their relative influence on transpiration may be determined by the method of least squares. In the case of alfalfa and amaranthus, the vertical component of radiation and the temperature enter into the determination of transpiration in the ratio of 1 to 1, approximately; and the corresponding ratios for vertical radiation and saturation deficit are approximately the same. On the other hand, in the case of rye, the radiation by this method of reduction shows less influence than either temperature or saturation deficit on the transpiration rate, which from 9 a. m. to 2 p. m. shows a marked departure from the graph indicated by the transpiration during the early morning hours.

Least-square reductions of the dependence of transpiration upon radiation and air temperature or upon radiation and saturation deficit do not account entirely for the observed transpiration, although a satisfactory agreement between computed and observed evaporation is obtained by the use of these environmental factors. This indicates that the plant undergoes changes during the day which modify its transpiration coefficient. In other words, our results support the conclusion of other investigators that plants under conditions favoring high evaporation do not respond wholly as free evaporating systems, even if bountifully supplied with water and no visible wilting occurs.

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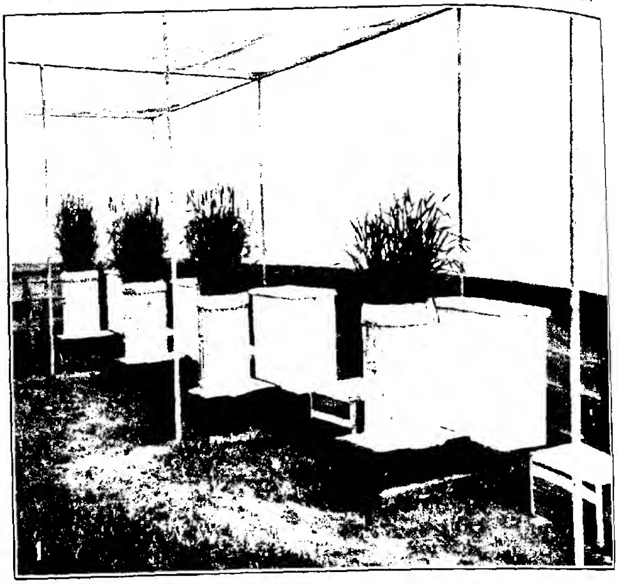
PLATE LIII

General view of the water requirement and transpiration experiments at Akron, Colo., on July 8, 1913. The large, screened inclosure in which the transpiration measurements were made in 1912 is shown at the right. The small instrument shelter in the foreground contained differential thermographs for measuring wet-bulb depression and solar radiation. The glass envelope surrounding the bulb of the radiation instrument may be seen on the top of the instrument shelter. At the left in the foreground is shown balance A, the front of the box open, and the recording device uncovered at the left. This balance is carrying a pot of sunflower. The next balance, B, carries the evaporation tank; balance C, another sunflower pot; and balance D, under the shade at the left, a third sunflower pot. The exposure of balances A and B, as used in the 1913 and 1914 determinations, is shown in this illustration.

Hourly Transpiration Rate on Clear Days



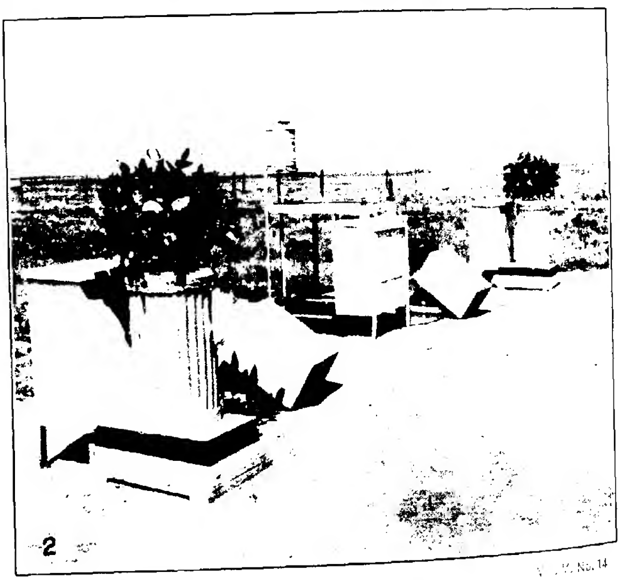


PLATE LIV

Fig. 1.—Wheat on automatic balances in the screened inclosure, July 3, 1912, showing the exposure and arrangement of the 1912 experiments.

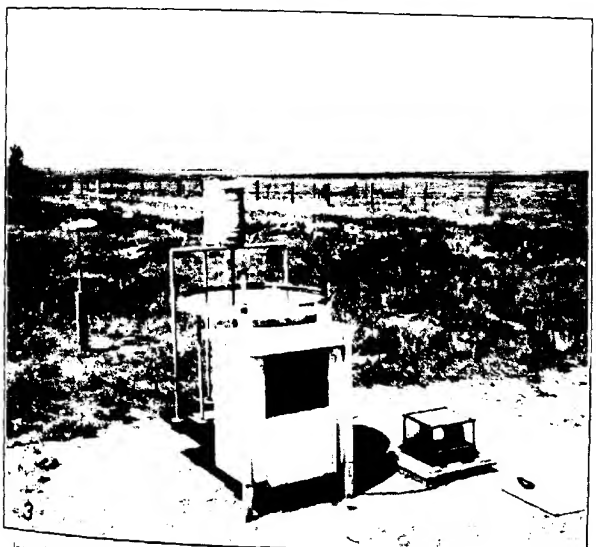
Fig. 2.—Automatic balances A, B, and C; A and C carry pots of cowpea and B carries the evaporation tank. This shows the exposure of the plants in the 1913 and 1914 transpiration experiments.

PLATE LV

Fig. 1.—A pot of alfalfa showing the growth and size of plants used in the transpiration experiments. The pot is 26 inches high and 16 inches in diameter.

Fig. 2.—A pot of *Amaranthus retroflexus* of the type used in the transpiration measurements.

Fig. 3.—Evaporation tank mounted on automatic balance. The reservoir is shown above in the back. The tank has an area of 6,540 sq. cm. and the water is maintained at a depth of 1 cm. The balance recorder is shown at the right and the anemometer at the left in the background.



EFFECT OF NATURAL LOW TEMPERATURE ON CERTAIN FUNGI AND BACTERIA

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The effect of the very intense cold of northern winters on the life and viability of fungi and bacteria does not seem to have been tested extensively, yet its importance in checking the spread of plant infections from these sources would appear to be very great.

Wolf[1] has shown that certain parasitic and saprophytic fungi remain present and alive in Nebraska orchards during autumn, winter, and spring. The majority of the species are saprophytic, the more common ones being *Alternaria* spp., *Cladosporium* spp., and *Penicillium expansum*. Only one parasite, the cause of leafspot, was present in abundance regardless of temperature. He found more spores in the air in neglected orchards than in well-cared-for ones and also found them to be much more abundant everywhere than commonly has been supposed. All his determinations were made by exposing plates at various places in the orchard and then carefully studying and determining the colonies after they had developed.

In the present study certain known fungi and bacteria were exposed in pure cultures to the low temperature of the winter months. The organisms were started upon nutrient agar in test tubes—i. e., allowed to grow at laboratory temperature for about one week after inoculation—and then these cultures were placed in a corncrib where there was a free circulation of air, but where they were protected from the rain and snow.

The tubes were inoculated between December 10 and 16 and were exposed in the outhouse on December 21, with the exception of *Actinomyces organicus*, which was not exposed until December 31. The cultures were undisturbed throughout the winter, during which time a minimum temperature of $-24°$ C. was reached. The medium did not dry up to any extent, but was rather moist when brought into the laboratory, as the frequent freezings and thawings seemed to impair the solidifying power of the agar.

On April 14 the cultures were brought into the laboratory and tested immediately for vitality. This was done by transferring part of the exposed culture to fresh nutrient-agar slants and allowing the new inoculations to grow at room temperature. In all cases except one the response to fresh agar was soon evident, but in the case of *Actinomyces*

[1] Wolf, F. A. The prevalence of certain parasitic and saprophytic fungi in orchards, as determined by plate cultures. *In* Plant World, v. 13, no. 7, p. 164-172, fig. 1; no. 8, p. 190-202, fig. 4-5. 1910.

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chromogenus the organism was probably killed by the low temperature. A large proportion of the conidia of both strains of *Sclerotinia cinerea* were found to be capable of germination. Table I gives the organisms and materials used and the results obtained.

TABLE I.—*Results of tests for vitality of various organisms after exposure to low temperatures (1912–13)*

Organism.	Medium.	Response of the mycelium.
Cephalothecium roseum	Synthetic agar	Excellent growth in 2 days, with production of spores.
Sclerotinia cinerea (Vermont culture).	do	Excellent growth in 36 hours; many conidia produced.
Alternaria solani	Lima-bean agar	Good growth after 2 days.
Cylindrosporium pomi	Synthetic agar	Good growth after 6 days; slow to start.
Sphaeropsis malorum	do	Slow growing at first; very good later.
Fusarium sp. of conifers	do	Excellent growth in 5 days over entire slant. Two trials needed to get results.
Glomerella rufomaculans	do	Started after 1 day and grew quickly.
Sclerotinia cinerea (culture from New Jersey Experiment Station).	do	Very good growth in 5 days.
Plowrightia morbosa	do	Excellent growth after 1 day.
Venturia inequalis	do	Good growth in 5 days with fruiting. Two trials necessary to get results.
Actinomyces organicus	Plain agar	Good growth in 2 tubes in 6 days.
Actinomyces chromogenus	do	No growth after a month. No growth on second trial.

The results secured during the winter of 1912–13 were so encouraging that further trials were made the following winter. Several organisms not tested previously were exposed with those first used, and the varieties used the first winter were tested on different media.

Since organisms in nature would be necessarily in a dry state during the winter and without much, if any, nourishment, it was the aim of the author to imitate for his pure cultures these conditions so far as possible. Accordingly, dry cultures of the various fungi chosen for this work, as well as the cultures on nutrient media, were exposed during the winter of 1913–14. These dry cultures were made by removing the growth of the fungus from the surface of the agar with a sterile needle and placing it in an empty, plugged, sterile test tube. A little of the agar was necessarily carried over with the fungus, but not enough to supply it with moisture or food for any length of time. In the case of the bacteria, some of the material from an agar slant was swabbed out with pieces of sterile cotton and placed in plugged, sterile test tubes. All of the cultures thus transferred were dried for 10 days in a warm closet in the laboratory before being exposed. It was expected that the question of food could be practically eliminated, while moisture was available only as it was carried by the air to the cultures.

The cultures were all prepared earlier the second season, and they were placed in the same corncrib on December 13, 1913. Along with the cultures was placed a Draper self-registering thermometer, in order that a comparative record might be kept of the temperatures to which the organisms would be exposed. This thermometer did not register accurately below $-27°$ C., so that during the three periods when the tempera-

ture fell below that point the official records of the Weather Bureau were considered as applicable to this test. The temperature was recorded from the date of exposure to March 1, 1914.

Table II summarizes briefly the extremes of temperature in the corncrib and also gives the lowest official record during each week of exposure.

Table II.—*Temperature records at Burlington, Vt., during winter of 1913–14*

Date.	Range in corncrib.	Lowest official record.
	°C.	°C.
Dec. 12–19, 1913	7 to −13	−14
Dec. 19–26, 1913	4.5 to − 9	− 9.4
Dec. 26, 1913–Jan. 2, 1914	− 4.5 to −23	[a] −24.4
Jan. 2–9, 1914	0 to −19	−20.5
Jan. 9–16, 1914	2 to −29	[b] −32
Jan. 16–23, 1914	− 4 to −22.8	−23.3
Jan. 23–30, 1914	7 to −20.5	−22
Jan. 30–Feb. 6, 1914	4.5 to −14	....
Feb. 6–13, 1914	2.8 to −26.6	[c] −30
Feb. 13–20, 1914	− 4 to −26	[d] −27.7
Feb. 20–28, 1914	10 to −23.3	[e] −25

[a] Jan. 1. [b] Jan. 14. [c] Feb. 12. [d] Feb. 16. [e] Feb. 25.

Tests were made of the vitality of the cultures on January 17, February 21, and March 27. These tests were made by transferring some of the growth from duplicate tubes of all the exposed cultures to fresh media of corresponding kind and holding at room temperature (19 to 22° C.) for several days. An abundance of tubes had been prepared, so that when the transfers showed no growth at the end of seven days two more exposed tubes could be brought in and tested. It will be noted that the first test for vitality was made on January 17, immediately following the extremely cold weather of January 13 and 14, when the official record was −30° and −32° C., respectively. Many of the organisms had withstood temperatures of −24° the previous winter, so it was not thought necessary to test any of them until they had experienced more severe cold. In Table III the results of these tests are summarized. Each sign used indicates the response of one culture; the plus (+) signs indicate growth, and the minus (−) signs mean that the culture was dead; "c" denotes contamination of the culture.

TABLE III.—*Results of tests for vitality of various organisms after exposure to low temperatures (1913–14)*

Organism.	Medium.	Date.	Result.	Date.	Result.	Date.	Result.	Date.	Result.
Sclerotinia cinerea	Synthetic agar	Jan. 17	+ +	Feb. 21	+ +	Mar. 27	+ +	Apr. 13	+ +
	Dry synthetic agar	17	+ +	21	+ +	27	+ +	13	+ +
Alternaria solani	Synthetic agar	17	− − − −	21	− − − −	27	− −	15	− − −
	Dry synthetic agar	17	+ +	21	+ +	27	− − + +	15	+ +
	Lima-bean agar	17	+ +	21	+ +	27	+ +	15	+ +
Cylindrosporium pomi	Synthetic agar	17	+ +	24	+ +	27	+ +	13	+ +
	Dry synthetic agar	17	− − − −	24	− − − −	27	+ − − −	13	− − − −
Sphaeropsis malorum	Synthetic agar	17	− − − −	24	− − − −	27	− − − −	13	− −
	Dry synthetic agar	17	+ +	24	− − − −	27	− − + +	13	+ +
Fusarium sp. of conifers	Synthetic agar	17	− − − −	24	− − − −	27	− − − −	13	− − − −
	Dry synthetic agar	17	+ +	24	− − − −	27	− − − −	13	− − − −
	Lima-bean agar	17	+ − − −	24	− − − −	27	− − − −	13	− − − −
Glomerella rufomaculans	Synthetic agar	17	+ +	21	+ +	27	+ +	13	+ +
	Dry synthetic agar	17	+ +	21	+ +	27	+ +	13	+ +
Plowrightia morbosa	Synthetic agar	17	+ +	21	+ +	27	+ +	13	+ +
	Dry synthetic agar	17	+ +	21	+ +	27	c c − −	13	− − + − −
Venturia inequalis	Synthetic agar	17	+ +	24	+ +	27	+ +	13	+ +
	Dry synthetic agar	17	+ +	24	+ +	27	− − + +	13	− + +
Cephalothecium roseum	Synthetic agar	17	+ +	21	+ +	27	+ +	13	+ +
	Dry synthetic agar	17	+ +	21	+ +	27	+ +	13	+ +
Colletotrichum Lindemuthianum	Synthetic agar	17	− − − −	21	− − − −	27	− − − −	13	− −
	Dry synthetic agar	17	− − − −	21	− − − −	27	− − − −	13	− −
	Lima-bean agar	17	+ +	21	− − − −	27	− − − −	13	− −
	Dry Lima-bean agar	17	+ +	21	+ + + +	27	− − − +	13	+ +
Ascochyta colorata	Synthetic agar	17	+ +	24	− − + +	27	+ +	14	+ +
	Dry synthetic agar	17	+ +	24	− − + +	27	− − +	14	− + +
	Lima-bean agar	17	+ +	24	+ +	27	+ +	14	+ +
	Dry Lima-bean agar	17	+ +	24	+ +	27	+ +	14	+ +
Phytophthora omnivora	Lima-bean agar	17	+ +	28	+ +	30	− −	15	+ + + +
	Dry Lima-bean agar	17	− − − −	28	− −	30	− −	15	− − − −
Pseudomonas campestris	Plain-agar slants	17	− −	Mar. 2	− −	30	− −	10	− −
	Dry cotton wads	17	+ +	2	c c − −	30	c − − −	10	c − − −
Bacillus melonis	Plain-agar slants	17	+ +	2	+ +	30	+ +	10	+ +
	Dry cotton wads	17	− −	2	c c − −	30	c − − −	10	c − − −
Actinomyces chromogenus (*Oospora scabies*).	Plain-agar slants	17	c − − −	2	− −	30	c − − −	10	− − −
	Dry cotton wads	17	− −	2	− −	30	c − − −	10	− − −
Actinomyces bovis	Plain-agar slants	17	− −	2	− −	30	− −	10	− −
	Dry cotton wads	17	+ +	2	− −	30	c c − −	10	− −
Actinomyces chromogenus	Plain-agar slants	17	+ −	2	− −	30	c − − −	10	− −
	Dry cotton wads	17	+ +	2	− +	30	+ +	10	+ +
Bacillus typhosus	Plain-agar slants	17	+ + + +	2	− −	30	c c − −	10	− − − −
	Dry cotton wads	17	+ +	2	c c c −	30	c − − −	10	− − − −

If the results of the exposures of these organisms to low temperature are summarized, it will be noted that five fungi, *Sclerotinia cinerea*, *Cephalothecium roseum*, *Glomerella rufomaculans*, *Venturia inequalis*, and *Ascochyta colorata*, lived over winter under all conditions of exposure; while four others, *Alternaria solani*, *Cylindrosporium pomi*, *Plowrightia morbosa*, and *Phytophthora omnivora*, lived over on some media but not on others. One fungus, *Fusarium* sp. of conifers, succumbed to the low temperature, while two others, *Colletotrichum Lindemuthianum* and *Sphaeropsis malorum*, were so weak that only under very favorable conditions would they respond to fresh media. Only two of the six kinds of bacteria exposed can be safely said to have survived—*Bacillus melonis* and *Actinomyces chromogenus*. Transfers from exposed cultures of *B. melonis* were found to agree in all distinctive characters with those given by Giddings. It is to be noted that this organism forms no spores. The growth of transfers from exposed cultures of *Actinomyces chromogenus* was very characteristic and hardly mistakable for any other organism. *In* regard to the other bacterial cultures, it may be said that they were more or less contaminated during the exposure; and although some of the transfers from them resemble the original growth, this was not well enough marked to prevent all suspicion. On the whole, the various organisms seem to withstand exposure better in a dry condition than when food and moisture are present.

Thinking that some of the organisms might die from natural causes other than the exposure to low temperature, the author retained part of the culture made for this test indoors as a check. They were kept in a cool room (14 to 20° C.) throughout the winter and tested for vitality late in March, 1914. In practically every case these cultures were living at that time, and no organism given in Table III can be said to have died otherwise than by exposure to low temperature.

No entirely satisfactory explanation has been offered as yet of the changes which take place in fungi and bacteria during or after exposure to extreme cold. The results obtained by the author throw little or no light on the manner of the freezing nor on the subsequent death. The present work is a record of the fact that certain fungi and bacteria are able to withstand extreme cold, while others succumb to it, but does not attempt to advance any theory as to the internal changes which contribute to the weakening or death of the organisms thus tested.

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